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An Investigation of Climatically Responsive Ultra-Low Energy Housing in Rural Scotland a Case Study

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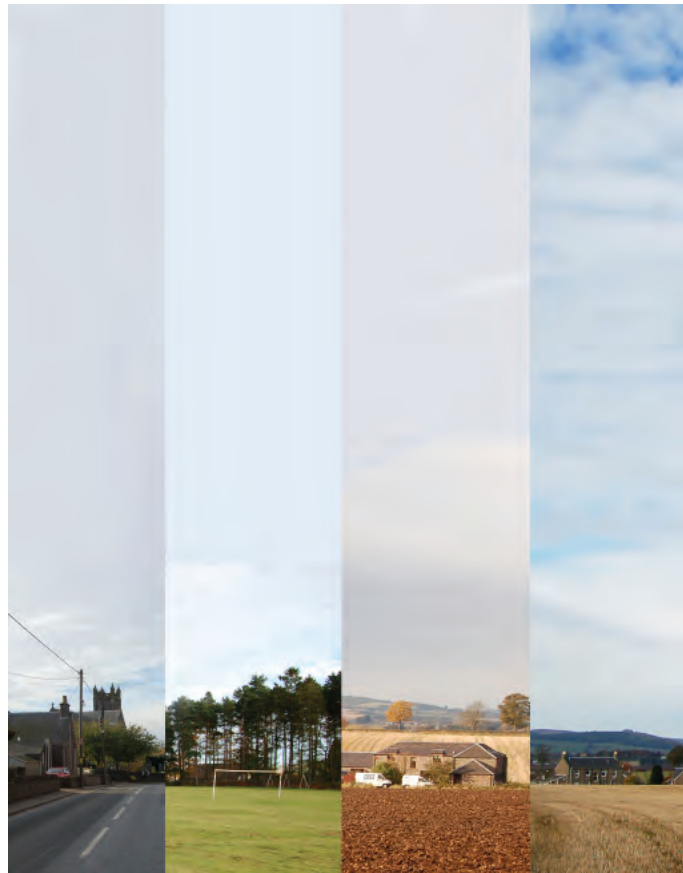
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An investigation of Climatically Responsive Ultra-Low Energy Housing in Rural Scotland: A Case Study

AN INVESTIGATION OF CLIMATICALLY RESPONSIVE ULTRA-LOW ENERGY HOUSING IN RURAL SCOTLAND: A CASE STUDY



Alexander David Pearson

A thesis presented in application for the Degree of Doctor of Philosophy in the
University of Dundee 2014

AN INVESTIGATION OF CLIMATICALLY RESPONSIVE ULTRA-LOW ENERGY HOUSING IN RURAL SCOTLAND: A CASE STUDY

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I also wish to thank all of my friends and family who have kept me motivated since starting the research. Special thanks go to my mother, Jill Pearson for keeping strong through hard times throughout my university career. Without her support this thesis would not have been possible.

Alex Pearson
July 2014.

Declaration

I hereby certify that the following thesis has been composed by me, that the work of which it is a record has been carried out by myself, and it has not been presented in any previous application for a higher degree.

Alexander David Pearson
July 2014.

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Abstract

In rural Scotland there has been a trend over the last 40 years towards mass market housing development which employs standardised housing models and suburban planning layouts. These have little relationship to rural landscape characteristics, regional climatic variations or historic rural communities. While they comply with current building standards, they fall significantly short of proposed improvements for energy performance which require all new homes to be 'Zero Carbon' by 2016/17 if practical and the European target of 'Nearly Zero Energy Homes' by the end of 2020. It is recognised that changes in legislation to reach these targets are falling behind schedule and energy analysis methods are flawed due to outdated calculation methodologies and imprecise climate data.

This research firstly provides an in-depth context for rural housing provision outlining the drivers and legislative requirements. The first section of the literature review investigates planning and current practice in housing, whilst the second section outlines the requirements for improved energy efficiency from the European to Scottish contexts.

The research then goes on to quantify the effects of regional climatic variation, in nine areas across Scotland, on space heating energy demand (SSHD). It utilises a best practice ultra-low energy housing prototype to demonstrate the requirement for regional solutions. All of the studies use a customised version of the Passivhaus Planning Package, an industry leading energy quantification methodology for heating energy calculations. A series of studies define the design envelope for achieving regional solutions by quantifying the relationship between the variation of design and form on the SSHD in the extremes of the Scottish regional climates. The variables relate to common metrics: orientation, glazing areas, roof forms and building typology. A separate study also compares the effect of Zero Carbon Homes and Passivhaus performance specification on SSHD. This method is developed further to determine the effect of building design on SSHD and heat load using seven contemporary Scottish Government exemplar housing designs. Improvements to the energy efficiency of these designs are made by considering variations to orientation and glazing design which are then discussed in relation to their impact on design quality. The results of the research demonstrate an increase of 81% in SSHD caused by regional variation across Scotland with up to a 29% increase from the UK average climate used in the UK's legislative analysis method SAP. This requires significant increases in insulation levels to retain SSHD performance. Alterations to the buildings orientation demonstrate an increase of 165% SSHD when deviating 180° from south, which is significantly higher than guidance suggests. The analysis of existing exemplar designs demonstrate a threefold increase in SSHD due to building form and orientation in some designs. The optimisation of the same designs illustrates a 45% reduction in SSHD through improved orientation and glazing design.

This thesis contributes to improving design thinking and assessment methodologies for new rural Scottish housing by highlighting the importance of climatically responsive design along with the consideration of appropriate energy efficient forms. The results of the thesis contribute to the debate surrounding the appropriate response of new housing in rural Scottish environments and highlights the importance of regional approaches and passive solar design for reduced housing energy use. This thesis contributes original knowledge on the effects of Scottish climate and building form on the SSHD of ultra-low

energy housing in Scotland. The extent to which a number of principle architectural planning and design parameters can be varied and optimised across different climatic regions will give architects and designers a more quantitative understanding of their design decisions and impact on space heating energy performance across Scotland.

Autobiographical Statement

This work began with an undergraduate Masters in Architecture (MArch) awarded in 2009 from the University of Dundee. The masters study investigated the design for a sustainable low carbon masterplan of houses on a site adjacent to Meikle, Perthshire. The group of 12 students developed four alternative strategies for the site which looked into energy generation, housing forms, urban morphologies, density and mixed land uses. Previous work in practice also underpins knowledge of the subject. Experience in RMJM Glasgow involved preparing a Sustainable Scottish Communities Initiative (SSCI) package for a eco town in Cardenden (St Andrew's House Scottish Government 2009c).

Over the period of the research other relevant competitions, courses and private work have also influenced the eventual outcome of the research. Some of this work is documented in the appendix. During the course of the research the author worked in and with various architectural practices which have all dealt with ultra-low energy and contextual design.

56 North was developed as a small practice between the author, Neil Burford and Joseph Thurrott. 56 North developed various competition entries and a proposal for a rural courtyard housing in Bridge of Earn. The most successful competition was the *100 Mile House* international design competition in Vancouver for which the practice proposed a Passivhaus ultra low energy house built from local materials for which won second prize (AFBC 2012). 56 North was based on previous collaborative work between the practice members that took the form of two research papers; *Between Country and Town: New Concepts in Sustainable Rural Housing* (2010) that explored the Meikle Masters project and *Minimum Energy Maximum Space: High Density Urban Family Housing* (2010) which developed a new ultra low energy urban housing model. The first paper was presented by Neil Burford at the 2010 *International Conference on Sustainable Architecture and Urban Development, Jordan* (Burford et al. 2010). The most recent collaborative design work was between the author, Neil Burford and Nicola Jackson in the *Larbert Loch Scottish Timber Competition* and the *Our Rural Island Home* Competition which proposed a close to Passivhaus £100,000 low energy home suitable for remote rural islands in Scotland (Architecture and Design Scotland (A+DS) 2012; Rural Housing Service 2014). This work allowed the use of contextually responsive design principles combined with a ULEH specification.

Additional work with Joseph Thurrott Architects (Passivhaus Certified) involved the design and construction of an ultra-low energy house and Plot 19 at the Scottish Housing Expo. This has included drawing work, site visits and construction meetings regarding lot 19 of the Scottish Housing Expo from an early stage in its development through to completion. The second main project in the practice was the development of the Maryville ULEH ultra-low energy house. The project was developed using PHPP at concept stage and was initially designed to perform to Passivhaus standard. However, during the design process the PH certification route was deemed too costly and time consuming to be viable. The house is now performing to the Passivhaus standard and post build certification is currently being explored. The experience from this ULEH project allowed for an application of theoretical and practical knowledge regarding low energy design through both design and onsite applications. This project led to one of the key methodological developments of the thesis. The use of the Passivhaus Planning Package (PHPP) and

Passivhaus principles as the benchmark for ULEH. The use of the PHPP on an onsite project required a detailed working knowledge of all aspects of the program and concept which highlighted its suitability as a research tool.

During the initial ultra-low energy design work on Maryville the author enrolled in the 2011 Passivhaus Certification Course. This allowed for the reinforcing of knowledge from the onsite Passivhaus project and led to a Passivhaus Certified Passivhaus Consultant qualification (Passive House Designer 2014). The Passivhaus certification exam required knowledge and manual execution of the PHPP key calculations and a detailed knowledge of the Passivhaus principles. As the research was already making use of Passivhaus and PHPP it also allowed for directed, detailed discussions on the direction of the research with one of the leading Scottish Passivhaus experts, Paul Tuohy.

Current practice work with Passivhaus Certified Garry Adam Architect Ltd concentrates on the development of both low ultra-low energy and regional designs around Scotland which currently acts as a method of developing the research findings in practice. The practice work undertaken throughout the thesis has significantly impacted on the direction of the research. The development of research and continual testing through practice has enabled the research findings to become more robust and applicable for use in architectural practice.

The presentation of the *'Defining the energy efficiency design envelope for regional Scottish Passivhaus dwellings'* paper at the 2012 Passivhaus conference in Hanover by the author allowed for the dissemination of the research in a wider forum, and allowed for feedback from international, professional and academic stakeholders on the research study (Pearson et al. 2012). The paper presented at the conference was then developed further for publication in the 2013 issue of *Intelligent Buildings International* entitled *'Ultra-Low Energy Perspectives for Regional Scottish Dwellings'* (Burford & Pearson 2013).

GLOSSARY OF ACRONYMS

Further Information

A+DS	Architecture and Design Scotland	
AS	Allowable Solutions	Carbon Offsetting defined by Zero Carbon Hub for English Zero Carbon definition
BRE	Building Research Establishment	www.bre.co.uk
BREEAM	Building Research Establishment Environmental Assessment Method	www.breeam.org
BSD	Building Standards Division	(Scotland)
CHP	Combined heat and power	
CLG	Communities and Local Government	
CO2	Carbon Dioxide	
CSH	Code for Sustainable Homes	
CSH L6	Code for Sustainable Homes Level 6	Previous England and Wales definition for Zero Carbon Homes
DECC	Department of Energy and Climate Change	
DER	Dwelling Emission Rate	Used in UK Building Regulations
DHW	Domestic Hot Water	
DOE	Department of the Environment	
EFPP	Extreme Fuel Poor	
EPBD	Energy Performance Directive	
EPC	Energy Performance Certificate	
EST	Energy Saving Trust	www.energysavingtrust.org.uk
FEES	Fabric Energy Efficiency Standard (ZCH)	
GHG	Green House Gasses	Greenhouse gasses as defined by the Kyoto protocol are; Carbon dioxide (CO ₂); Methane (CH ₄); Nitrous oxide (N ₂ O); Hydrofluorocarbons (HFCs); Perfluorocarbons (PFCs); and Sulphur hexafluoride (SF ₆)(United Nations 2008)
Gt	Heating Degree Days	Degrees per hour below 15.5 °C per annum in (kKh/a)
HEEPS	Home Energy Efficiency Programmes for Scotland	
HL	Heat Load (w/m ²)	Heat Load determines the maximum amount of heat required to heat the building in the worst of two scenarios. The first is a mild overcast day, with little solar gains available. The second is a cold, clear day. This measurement is used in PH to determine if the building can be heated using hot air only- <10 w/m ²
kgCO2/m2/a	Carbon Emissions per meters squared per year	
kW	Kilowatts	
kWh	Kilowatt hours	
kWh/m ² /a	SSHD Units-Kilowatt hours per meters squared per annum	
kWh/m ² /yr.	SSHD Units-Kilowatt hours per meters squared per annum	
LCBSSS	Low Carbon Building Standards Strategy for Scotland- The Sullivan Report (2007)	
LCT	Low Carbon Technologies	
LZCGT	Low and zero carbon generating technology; Wind turbines; Water turbines; Heat pumps (all varieties);Solar thermal panels; Solar photovoltaic panels; Combined heat and power units (fired by low emission sources); Fuel cells; Biomass boilers/stoves; Biogas	
LZCT	Low and Zero Carbon Technologies	
MVHR	Mechanical Ventilation with Heat Recovery	
NZEB	Nearly Zero Energy Buildings defined in EPDB	

GLOSSARY OF ACRONYMS

Further Information

PAN	Planning Advice Notes	
PH	Passivhaus	
PHI	Passivhaus Institute	http://passiv.de/en/
PHPP	Passivhaus Planning Package	Excel based Passivhaus calculation methodology software for estimating heating and electrical demand.
PV	Photovoltaics	
RHS	Rural Housing Service	
Rural	Scottish Definition see http://www.scotland.gov.uk/Resource/Doc/933/0103167.pdf	
SAP	Standard Assessment Procedure (the Government approved methodology for the energy rating of dwellings)	UK Calculation methodology for different aspects of residential performance to demonstrate regulation compliance.
SEDA	Scottish Ecological Design Association	
SSCI	Scottish Sustainable Communities Initiative	
SSHD	Specific Space Heat Demand, Heating energy demand (kWh/m ² /a)	Measures the heating requirement in kWh over a year per m ² of floor area. This translates directly into electrical meter demand if heating was provided through 100% efficient electrical heating.
SUF	Solar Utilisation Factor (%)	Percentage of solar gain used for space heating (below 20°C)
Sustainable	See: Brundtland, G.H. (1987) Our Common Future, Oxford University Press, Oxford.	
TER	Target Emission Rate	Used in UK Building Regulations
Typology	Housing Unit Formal Arrangement i.e. Detached or Terrace	
UK	United Kingdom	
ULE	Ultra Low Energy	
ULEB	Ultra Low Energy Buildings	
ULEH	Ultra Low Energy House/ Housing	
U-value (W/m ² .k)	The standard measure of the thermal transmission of a building element	Commonly used to determine the thermal performance requirement in legislation or low energy approaches.
W/m ²	Measurement for Heat Load	
Window Heat Balance		The window heat balance represents the annual heat balance of a particular window or group of windows over the course of a year- Heat Gains\ Heat Losses
ZC	Zero Carbon	
ZCH	Zero Carbon Homes	

1. INTRODUCTION

European legislation regarding energy use for new buildings requires housing to become “Nearly Zero Energy” (NZEB) by the end of 2020 (Commission of the European Communities 2008). This target has a major effect on the design and construction of new homes. A key stage to meeting this requirement is the target for all new Scottish homes to be Zero Carbon by 2016/17 if practical, a target which is already under threat (Scottish Government 2007a; Scottish Executive 2013a). These targets are in reaction to the European pledge to reduce its GHG emission by 20% by 2020 (in comparison to 1990 levels), as part of the extended Kyoto agreement (Europa 2011; UNFCCC 2013). The energy use through homes has a major part to play in reducing GHG emissions; in 2011 homes were responsible for 27% of the final energy requirements in Europe. In the UK, space heating accounts for 60% of the total domestic energy use, therefore, reducing the energy demand of UK is a major housing issue in the ability of the UK to meet its GHG emission targets without penalty (Department of Energy and Climate Change 2012a; Department of Energy and Climate Change et al. 2011). While Scotland’s climate is generally harsher than much of the UK, there are the added issues concerning the extreme variations in climate across Scotland’s regions due to different factors which directly affect the energy use in housing across the country (BRE 2011c; Met Office 2013g). The current UK Zero Carbon Homes (ZCH) approach is to reduce carbon emissions through a mixture of increased building fabric, renewables and carbon offsetting (Zero Carbon Hub 2014e). The ZCH offsetting approach has been criticised as this devalues the building energy performance (Kibert & Fard 2012, p.634). The ZCH determines maximum space heating demand far higher than that of established low energy approaches (Economidou 2011; Zero Carbon Hub 2014c). The overall approach differs from leading low energy concepts such as Passivhaus (PH) which reduces space heating energy demands by a factor of ten through only increased fabric performance levels and mechanical ventilation systems (B. Steinmüller 2008). The methodology used for certification of ZCH in the UK is the Standard Assessment Protocol (SAP). The SAP uses average climate data to estimate building performance and carbon emissions (BRE 2014). The effect of harsher than average climates on many Scottish buildings means that the already proven gap in estimated and actual building performance will be larger in Scotland (Zero Carbon Hub 2014d). There are currently limited resources on the design of low energy housing in Scotland and there is little guidance available for architects, planners and legislators regarding the effects of regional climatic variation on energy demand in housing.

By 2035, Scotland’s population is projected to increase by 10%, this increase is proportionally higher in rural areas with populations in some accessible rural areas increasing by 32% (Skerratt et al. 2012). This is in part due to increases in the numbers of holiday/second homes and the number of individuals who wish to work from home and has the knock on effect of increasing housing costs for rural workers (Sustainable Development Commission & Dwelly 2009; S. A. H. Scottish Government 2005b; SRUC 2013). Combined with higher than average rural fuel costs compounded with energy price increases is putting more and more of the rural population into fuel poverty (Scottish Executive 2012i; Underwood 2007). The increase in population and current lack of affordable homes strongly suggests the requirement for more new rural, energy efficient homes in some areas (The Scottish Parliament 2009).

Until recently traditional rural housing forms have developed incrementally over time which has led

to the development of a 'vernacular' language with planning, construction methods and details developed appropriate to the climate of the different regions. In contrast current mass market housing in both urban and rural areas use planning and architectural models that have little relationship to context, climate or the historical traditions of an area. House designs are generally based on a misunderstood use of historic building styles and languages from different periods but usually drawing from late Georgian and Victorian rural housing examples. This usually results in housing with complex forms and consequently high surface



Figure 1- Fochabers (Google Maps 2014)

to volume ratios with inefficient spatial planning that does not take full advantage of heat gains leading to higher space heating requirements. Since the 1980s, these developments have resulted in the use of standardised solutions that mainly take the form of single detached house types, organised within organic, low-density suburban style development in contrast to the clustered and often highly organised traditional rural planning typologies found in communities such as Ullapool and Fochabers (Scottish Executive 2013c, p.117; Maudlin 2009a)[Figure 1]. Until recently, with little exception, mass market house planning has given little recognition to orientation, density, lifestyle, contextual response or the drive for the development of an appropriate identity for communities in rural areas. Planning guidance for rural areas specifically highlights these issues and actively discourages suburban development (Scottish Government 2005; S. A. H. Scottish Government 2005b). There are Government endorsed examples that aim to demonstrate the alternative to suburban development and showcase new planning principles, however, the uptake on these suggestions is very limited (St Andrew's House Scottish Government 2009d; St Andrew's House Scottish Government 2011i). Within Scotland there are exemplary designs which reference and integrate into the context appropriately. These residential developments tend to reference traditional building forms and positioning within the landscape (Scottish Government 2005). There are a range of small architectural practices throughout the country that have gained praise for their high quality privately commissioned houses through the *Inspirational Designs* database (S. A. H. Scottish Government 2012d). However, the majority of these appear to be designed with an intuitive rather than calculated approach to environmental design. There are few examples of appropriate contextual, affordable low energy houses in rural Scotland. Development within the Scottish rural landscape has a long lasting legacy on the identity of Scotland. It is a priority to utilise appropriate development strategies with the impending future requirement for development. Therefore there is now a critical need to develop new sustainable, economic, low-energy rural housing models (Scottish Government 2012c). In order to achieve this it will be necessary to better understand the implications of developing more nuanced and qualitative, low energy housing typologies that respond appropriately to the various regional Scottish climates, landscapes, and economic contexts. There is currently a lack of holistic thinking when designing mass-market rural housing in Scotland which is impeding the desire of the country

to reduce its energy demand. In order to quantitatively reduce energy requirements by responding to variations in regional climate effectively an alternative approach to ZCH and the SAP analysis methods must be utilised.

1.1. Historical Development of Low Energy Housing and Sustainable Communities in Europe and North America

1.1.1. The Early Science and Practical Application of Solar Technologies

[Figure 2]

Since antiquity, climate change and the need to conserve scarce fuel resources to satisfy the demand for available and inexpensive energy for heating has prompted the continual development of passive and active solar technologies for buildings. Early civilisations, such as the Greeks and Romans, without the need for energy for power and spurred by the depletion of wood fuel sources invented ingenious strategies for utilising energy from the sun to heat buildings. These ranged from new building technologies such as the invention of the solar furnace to ingenious spatial and city planning concepts relying on optimised solar orientation.

Widespread food shortages caused by a period of global cooling between the 16th and 18th centuries led to numerous innovations by French, Dutch and English farmers to prolong growing seasons for plants. In 1699, Switzer and de Duillier developed practical experiments for improving fruit walls based on slope and orientation to maximise solar gain (Wolf 1862). In England, the Duke of Rutland invented the first greenhouse at Chatsworth House in 1714 to trap solar heat, which was later improved by Adamson with the introduction of multiple layers of glass, insulating curtains and thermal storage (Duchess of Devonshire 1999). In 1767, Saussure carried out the first empirical experiments using a 'Sun Box' to study the relationship between the heating effects of the sun through glass and subsequently its conservation through the use of insulation (Butti & Perlin 1980). Later, Langley established the scientific basis for the elementary properties of energy exchange (Walcott, 1911). The first practical application of the conservation of heat using insulation and advanced glazing can be traced back to 1883 with the construction of Fridtjof Nansen's polar exploration ship the Fram (Passipedia 2012b).

In 1910, William Atkinson applied the techniques of the 'Sun Box' in the design of a Sun House from which he developed a rational method for understanding the solar heating effects of rooms based on opening size, position and orientation. In 1932, the RIBA published studies on the optimisation of solar collection due to building orientation and went on to develop the Heliodon – an empirical tool designed to simulate the sun's movements throughout the year to help architects test the environmental properties of buildings using physical scale models (Dufton & Beckett 1931).

[Figure 3]

While this work was to pave the way for the first generation of passive solar optimized houses a parallel process of innovation had been developing active solar technologies that was to influence a divergent approach to low energy housing. The Climax Solar Water Heater patented by Kemp in 1881 and later

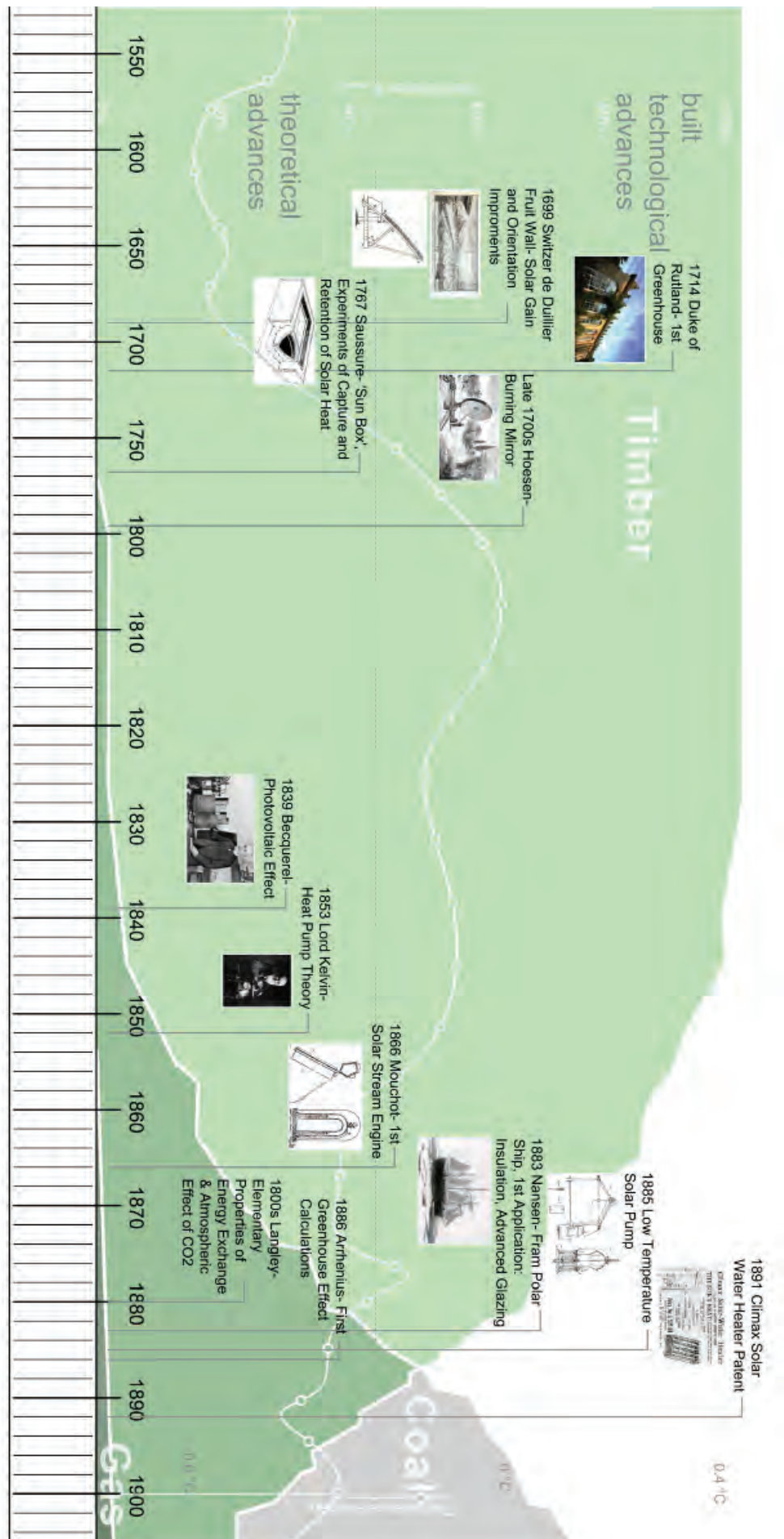


Figure 2 -Early developments in the science and practical application of solar powered technologies.

improved by Walker in 1902 led to the 'Day and Night Heater' invented by Bailey in 1909 (Butti & Perlin 1980). This invention revolutionised the industry by separating the heating and storage elements of the system leading to the design of the first active solar house by MIT in 1939. The heat pump originally proposed by Lord Kelvin in 1852 was first used in the late 1920s by TGN Haldane to provide all the hot water and domestic heating requirement for his farm in Scotland (Oppenheim 1981). In the 1970s water to air heat pumps were extensively used in experimental low energy housing for heating and hot water supply. The air to air heat pump used to extract heat from ventilation air was used in the Livingston House, Edinburgh, 1978 and the Salford Prototype Houses designed by Dr J E Randell, University of Salford in 1978 (Oppenheim 1981). While the Livingston House had minimal insulation, the Salford House was insulated to standards equivalent to the projected fabric U-values of the UK's Code for Sustainable Homes Level 6, with a similar fabric efficiency standard becoming mandatory in the 2016 building regulations showing the important relationship between energy conservation and efficiency (Brown et al. 2010). Air to air heat exchangers are an intrinsic component of ultra-low energy housing approaches today, such as Passivhaus and Minergie, have had the most radical and controversial implications on design as they require very airtight building envelopes and mechanically controlled ventilation to achieve high levels of efficiency. However, concerns over air quality, effects on human health and occupant behaviour are factors that are preventing the more widespread application of this approach in the UK.

One of the most significant technologies to impact on contemporary low energy housing has been the discovery of the photovoltaic effect first observed by Becquerel in 1839, which found a practical application in the first modern solar cell manufactured by Bell Laboratories in 1954 in America. Shortly after in 1958, Vanguard I, the first solar powered satellite was launched. In 1974, J. Baldwin, at Integrated Living Systems, co-developed the world's first building in New Mexico heated and otherwise powered by solar and wind power exclusively (Danitz & Cousineau 1994). Up until this time the principle and most practical source of power delivery to housing was through centralised nuclear, hydro or coal fired power generation distributed through national power grids. In 1991, in an effort to reduce carbon emissions by 20% of 1990 levels by 2012, Germany began its "1000 Roofs" program, in which the government gave subsidies to people, to cover the cost of solar rooftop PV installation to generate power. Within a few years, 2000 grid-connected solar panelled rooftops were installed with the program expanding into the "100,000 Roofs" by the end of 2004 and by 2011 had achieved a million grid connected PV systems (Stuart 2011). To date, feed-in tariffs in Europe have fuelled huge growth in solar PV and wind industries which are now at the centre of current UK renewable power generation and housing policies (GOV.UK 2013d). Today, balancing supply and demand for renewable power generation has become critical with a major emphasis now being placed on developing more effective power storage systems such as batteries and hydrogen fuel cells.

1.1.2. First Generation Low Energy Houses – 1939 to 1959

[Figure 4]

The first integrated low energy houses weren't developed until as late as 1939 during which time two approaches were to emerge. Frank Lloyd Wright in the Solar Hemicycle in 1943 and Louis L Kahn in the Direct Gain House in 1947. These examples explored empirical methods for understanding the relationships between building form and energy efficiency (Hastings & Wall 2007). This work, started by Keck, Hutchison and Brown, established some of the basic principles for controlling heat (Roth 2003). They showed that solar orientated houses have much greater diurnal temperature swings requiring effective control and that large auxiliary heating systems were required to compensate for heat losses at night through the large south facing glass facades. Brown developed the first understanding of the effects of thermal mass and thermal storage in being able to flatten out large temperature differences in solar heated houses.

A scientific approach to the design of low energy solar housing began in 1939 and culminated in 1959 with four houses constructed and tested by MIT using both passive and active solar generation and storage technologies (Butti & Perlin 1980). These prototypes used different combinations of active solar collectors and thermal storage; all rigorously monitored, providing the first scientific benchmark for solar housing approaches (Bouamane & Jones 2012). Significantly, the first prototype house constructed in 1939, with minimal insulation values compared to standards today, showed that no additional heating was required during its two years of operation, other than that gained from the sun. It ultimately failed to become mainstream due to the uncompetitive costs of the technology due to the over-sizing of the thermal water storage to compensate for fabric energy losses. While North America was developing a technical, scientific approach to individual solar houses, Europe was struggling with massive post-war housing shortages and rising fuel costs. In 1920, French urban planner Augustin Rey had shown for the first time the implications of south orientated solar planning on reducing urban densities and how this would contribute to urban sprawl. Rey also invented the concept of the Heliothermic axis, which defined the relationship between solar duration and air temperature, later adopted by Le Corbusier in the plans for La Ville Radieuse, which Corbusier saw as one of the most important principles in solar urban design (Montavon et al. 2006). In Germany, modernist architects Gropius, Scharoun, Rudolf-Henning and Bartning developed the Zeilenbau Plan for a new housing district in Berlin based on Rey's density studies (Curtis 1996). The linear, east-west facing blocks were designed to maximise density whilst giving all rooms within the plan equal access to sunlight. However, this proved to be unsuccessful with the open spaces between the blocks receiving more sunlight than the apartments themselves. Following this, strategies for large solar planned districts changed to south-orientated blocks but with the inherent disadvantage of the constrained orientation. The most successful of these was the Werkbundsiedlung at Neubühl developed in 1932 by a cooperative of seven young Swiss architects who had been instrumental in the founding of CIAM (Adler et al. 1978). In Scotland, the Edinburgh Gogarbank House by Robert Matthew was "*internally, one of the world's first eco houses*" designed in 1957 (Historic Scotland 2009b, p.54; Scotsman 2011; Bell Ingram 2012). The house was sited in an existing walled garden to improve

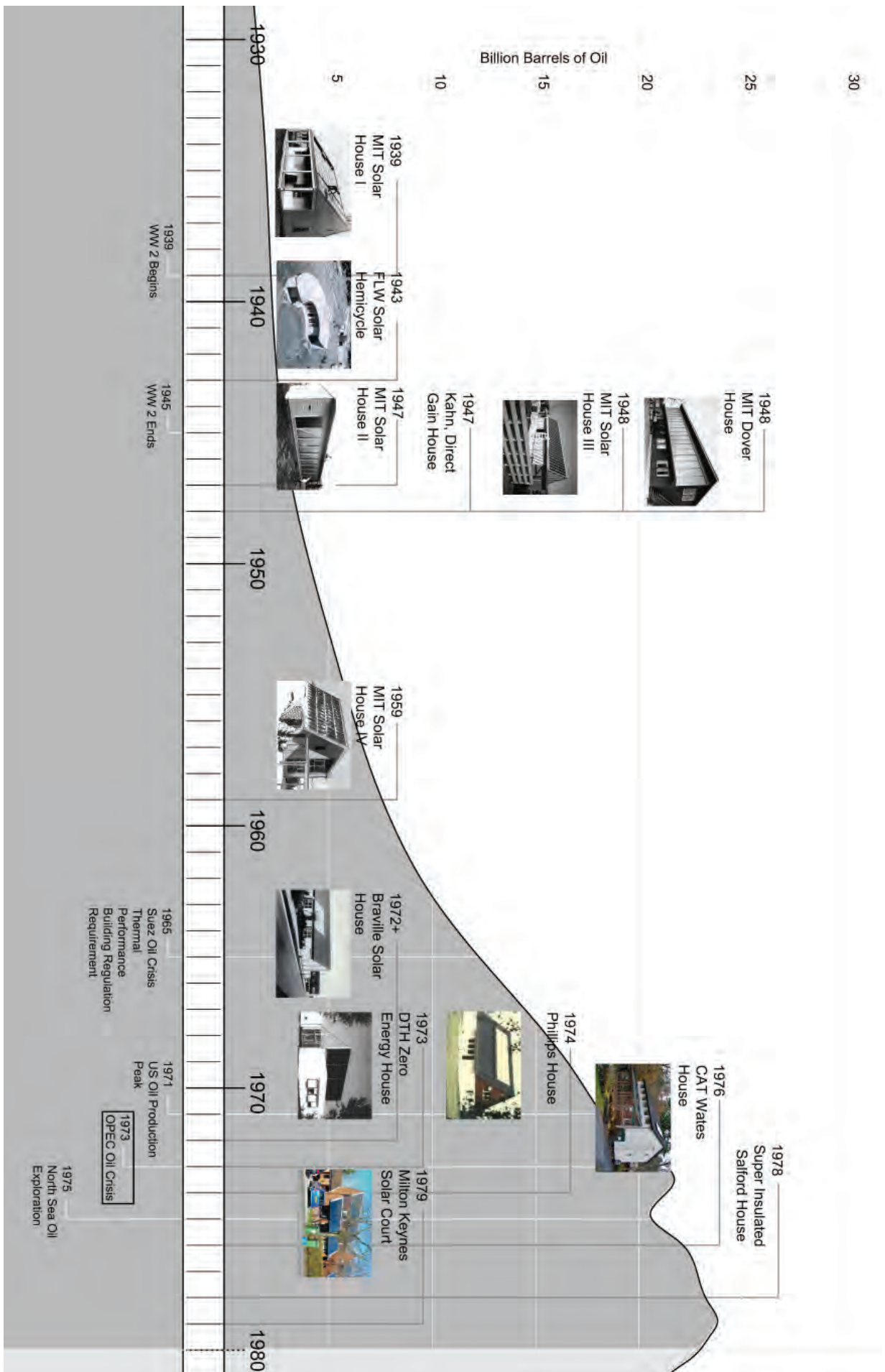


Figure 4- Timeline of First and Second Generation Low Energy Houses

the micro climate surrounding the house (Glendinning 2008). One of the key design criteria was for it to have a strong relationship to the surrounding gardens which was achieved by a courtyard plan that ensured that all four wings received maximum sunshine (Scotsman 2011). Both in Europe and America further attempts at planned solar communities and experimental solar houses largely stopped for several decades due to the inability to compete with significantly cheaper fossil fuels and a more affluent society.

1.1.3. Second Generation Low Energy Houses – 1972 to 1980

In 1973, the Organization of the Petroleum Exporting Countries (OPEC) oil embargo provided the incentive for a new wave of research into energy efficient housing. In the UK, the establishment of the Milton Keynes Energy Park between 1972 and 1981 provided some of the most detailed UK based research across a number of fields, focusing principally on renewable technologies and improved construction techniques imported from Scandinavia (Edwards 1990). In Europe, development of ultra-low energy houses produced the DTH Zero Energy House built at the Technical University of Denmark in 1973 the - first zero energy house - and the Phillips Experimental House, Germany, built in 1974 (Esbensen & Korsgaard 1977; B. Steinmüller 2008). These houses had early combined computer-controlled ventilation, heat exchangers and extensive computer monitoring and used no energy for ventilation and heating (D. B. Steinmüller 2008). The Wates House, constructed at the Centre for Alternative Technology (CAT), Wales in 1976 employed a heat pump and heat exchanger in combination with a very high specification thermal envelope using one-fifth the energy compared with a standard house of the time and remains the highest specification thermal envelope in the UK to date (Oppenheim 1981). These houses established the basic principles and theories that now form the basis for the world leading Passivhaus standard for the design of ultra-low energy buildings. The Solar Court (Linford Project) and the Pennyland projects based in Milton Keynes between 1979 and 1983 demonstrated significant research in building technology and solar planning. The Solar Court project analysed three different technical approaches to solar housing with various combinations of solar hot water collectors, storage tanks and heat recovery. The best contributed 62% of the energy for the house through solar means (Fuller et al. 1982; PRP Architects & NHBC 2010). The Pennyland Solar housing scheme focused on urban and housing layouts to improve heating energy reduction. The research used shadow prints, which are an extension of the Heliodon testing method. The study concluded that houses could be orientated south $\pm 40^\circ$ and still take advantage of solar gains (Fuller et al. 1982, p.15). Following these major advances in understanding and technology, solar and low energy housing research in the UK once again slowed with the oil surplus in the mid 1980's (Bainbridge & Haggard 2011). Further significant research did not emerge until the 1990's with the heightened awareness of climate change, unsure future of fossil fuels and rising fuel costs. This latest drive in the development of low energy housing, particularly in Europe, originated with the 1992 World Summit in Rio de Janeiro followed by the 1997 Kyoto Protocol, which was incentivised at governmental levels by the establishment of the EU's climate and energy targets to reduce global carbon emissions.

1.1.4. Third Generation Low Energy Houses - Current Trends and Practice

[Figure 5]

Many alternative approaches to low energy housing and building codes have emerged across mainland Europe in the last 20 years. The majority of these standards have different aims and use different calculation methodologies. Terminologies are mostly non-interchangeable and so the different codes are not easily comparable (Economidou 2011). Recent research in the UK has focused on broad sustainable approaches to housing and offsetting carbon emissions using active low carbon technologies, reflected in the building regulations since 2006 (Communities and Local Government 2009). Sue Roaf's Eco House built in 1995 is one of the UK's first net zero energy houses with the first UK domestic solar PV installation (Roaf 2003). It also utilised a solar sunspace, solar-thermal hot water generation, high levels of insulation, thermally massive construction and triple glazing. The Southwell House (1995), designed by Brenda and Robert Vale was a prototype for future sustainable housing being designed to be net autonomous in heating and power energy demand, water supply and waste treatment – effectively the UK's first sustainable off-grid building (Vale 1975). In 1998, the Vales developed this concept for a group of five grid-connected, earth-sheltered, ultra-low energy terraced houses at Hockerton, Nottinghamshire. This sustainable community of houses gained the majority of its power from two wind turbines and a solar PV system resulting in very low total energy requirement of 11 kWh/day with 33% for space heating, requiring 10.9 kWh/(m²a) specific space heat demand (SSHD) (Energy Saving Trust 2003; Strong 2003a; Hockerton Housing Project 2012). BedZed, London was the UK's largest mixed use, carbon-neutral, high-density development that set new standards in sustainable building when constructed for the Peabody Trust in 2002 (Dunster et al. 2007). The 82 affordable dwellings consisting of flats, maisonettes and town houses, with approximately 2500 m² of workspace and offices were arranged within an inventive cross section that optimised orientation and external spaces. The development was powered by a biomass, combined heat and power plant with additional PV electrical generation, onsite sewage treatment, rainwater recycling and natural wind driven ventilation creating a largely autonomous urban 'island'. The Creative Energy Homes (CEH) project constructed on the University Park Campus of the University of Nottingham is a showcase of seven innovative state-of-the-art energy efficient homes of the future constructed between 1999 and 2012 (University of Nottingham 2012). These include the David Wilson House, 1999, BASF House, 2008, E.ON 2016 House, 2009, The Tarmac Homes, The Nottingham House built for the Solar Decathlon Europe 2010, and the Mark Group House, 2012. The later houses are designed to various CSH standards, degrees of innovation and flexibility, allowing the testing of different aspects of modern methods of construction sustainable and renewable technologies. These have been instrumented and occupied providing comprehensive post occupancy evaluation data (University of Nottingham 2012). Recently, CEH have implemented a residential hydrogen-based micro-grid to provide mid-term storage of renewable energy.

The Building Research Establishment (BRE) has been at the forefront of UK policy making in low energy housing and has provided much of the scientific sustainable housing research in the UK since 1997. The Integer House constructed in 1998 marked the start of the BRE's focus on sustainable housing (Strong 2003b). This later led to the establishment of the BRE Innovation Park in Watford, London in 2005. BRE have

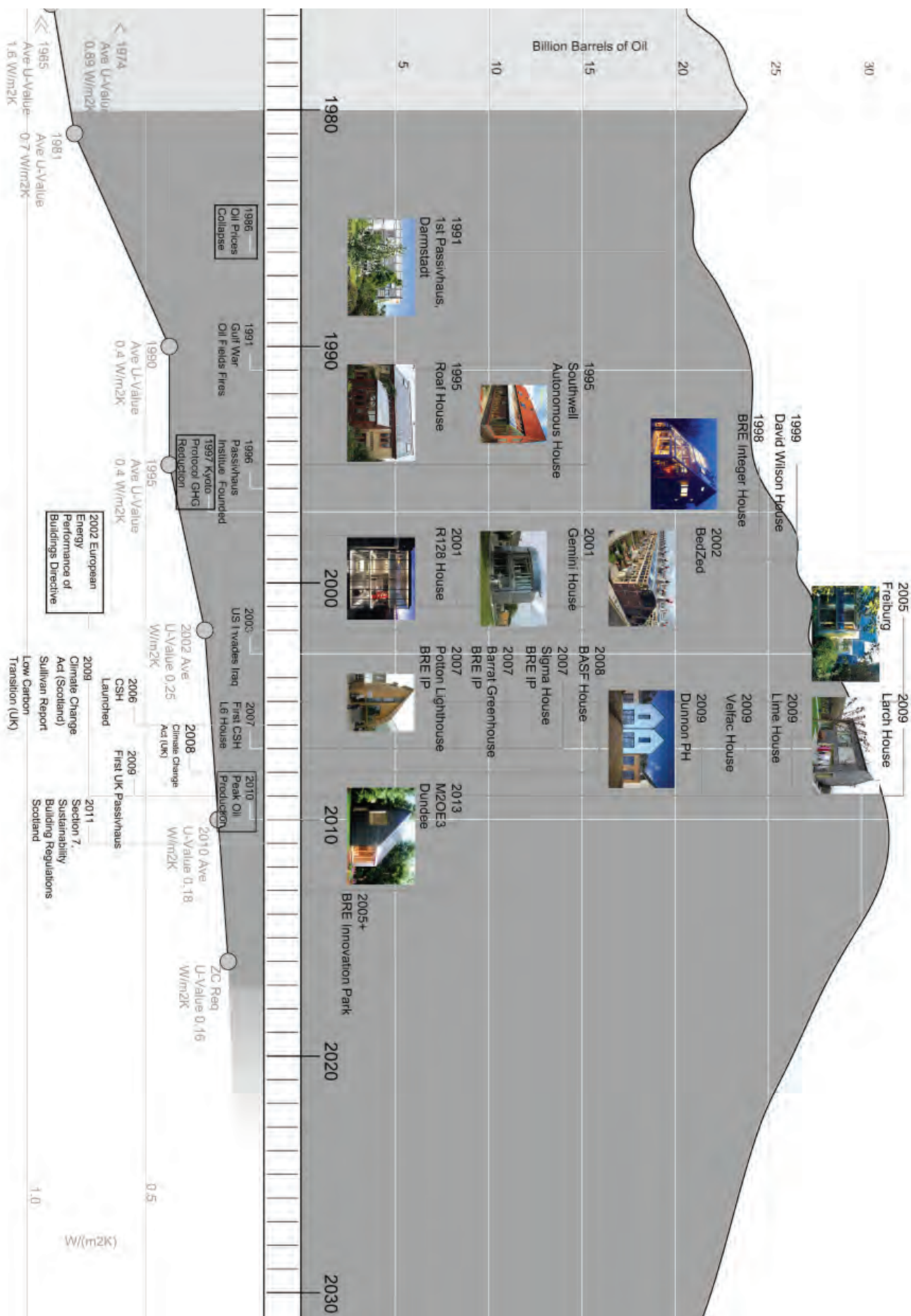


Figure 5- Timeline of Third Generation Low Energy Houses

also been instrumental in the formulation of the UK's policies on future low energy housing performance which has resulted in the Code for Sustainable Homes legislation 2006 (CSH). This defines the term Zero Carbon Homes (ZCH), a zero emission house that produces as much energy as it consumes but does not include energy for cooking or appliances (un regulated sources) (Zero Carbon Hub & Marjewycz 2011). Many of the early CSH prototype examples designed and built in collaboration with some of the UK's largest housing developers are at the BRE's Innovation Park and include the Pottton Lighthouse (CSH Level 6, 2007), Barratt Green House (CSH Level 6, 2007) and the Stewart Milne Sigma House, (CSH Level 5 2007)(BRE 2010). BRE Ravenscraig Scotland, was established in 2012 to create a demonstration sustainable development showcasing the new sustainable housing solutions and the products and technologies that will help meet the future energy requirements for Scotland (BRE 2012). Recently, The Housing Innovation Showcase in Dunfermline, Scotland completed in 2012, a private/public sector initiative developed by Kingdom Housing Association is Scotland's largest development showcase of affordable sustainable housing demonstrating modern methods of construction and sustainable building practices (Scottish Executive 2012e, p.54; Housing Innovation Showcase 2013).

Going beyond the UK's 2016 environmental building standards, Macro Micro Studio, University of Dundee Botanic Gardens is a Passivhaus compliant, off-grid building that relies solely on renewable energy sources and storage as the only means of generating space heating, hot water and power (Burford 2012). It is designed to address issues surrounding the provision of ultra-low energy buildings in remote and difficult to access rural and island contexts such as those found in the North and West of Scotland where off-grid energy supply and storage are major issues.

In Europe, there has been a similar divergence of approaches to low energy housing. The German Passivhaus concept developed by physicists Bo Adamson and Wolfgang Feist, was first tested in a terraced house in Darmstadt in 1991 (Feist 2006). Using a fabric first approach to energy conservation, the stringent energy use requirements focused on achieving a very high specification thermal envelope with mechanical heat recovery ventilation. It resulted in heating demands equivalent to just 10% of a standard house setting the current benchmark performance for affordable ultra-low energy housing in mainland Europe. Rigorously tested and benchmarked through the CEPHEUS Programme there are now over 37,000 Passive Houses in use worldwide (as of 2012) (Schnieders 2003; Passipedia 2012b). The German, zero emission, R128 house built in 2001, provides a radically different technological solution using no energy for heating whilst having completely recyclable building materials and fully glazed facades (Blaser 2001). The heating of the building relies entirely on solar gain with excess heat transferred to a heat store using heat exchangers and a water-cooling system. The SOLTAG Energy Housing at Horsholm, Denmark, developed for the EU's 6th Framework Programme is a prefabricated, solar-based energy-autonomous housing unit that can be added to the existing building infrastructure (Jenson & Thomsen 2008). Designed as a roof refurbishment system for existing buildings, it operates autonomously from the host building with energy for domestic hot water and heating being provided from renewable micro-generation technologies. It provides a sustainable concept for densifying city centres, developing existing rooftops as 'new' building plots. The Velfac Active House in Aarhus, Denmark, designed by Aart Architects and Rikke Lildholdt in 2009 goes beyond zero emissions producing more energy than it uses (Purcell 2009). The 50m² of solar panels have the capacity to generate

excess electrical energy enabling the payback of the build energy costs within 30 years by feeding energy into the national grid. Similarly, the Energy-Plus House at Thening, Austria in 2001, produced more energy from renewable energy sources over the course of a year than it imported from external sources with the house consuming only 1/3rd of the electrical energy produced from the 86m² PV array (Hastings & Wall 2009). A combination of micro-generation technology and low-energy building techniques, such as passive solar building design, insulation and careful site selection and placement were used to achieve Passivhaus energy conservation efficiency and excess electrical energy generation. The Gemini House constructed in Weiz near Graz, Austria in 2001, designed by Roland Mosl, advanced solar PV architecture by developing a cylindrical house that could rotate to track the path of the sun, optimising the efficiency of the 150m² PV panel façade (Mosl 1993). The Plusenergie[®] haus concept is at the heart of Europe's largest solar community located in the Vauban district of Freiburg which has emerged as a model for sustainable living (Zero Carbon Hub & Marjewycz 2011). Freiburg the solar capital of Europe, exemplifies the integration of renewable energy design from the level of public policy and urban planning to the details of architectural form and technologies. The goal is to create a sustainable region where CO₂ emissions are reduced in the areas of transport, waste, industrial production and energy use. Going beyond this, the 2000-Watt Society is an environmental vision, first introduced in 1998 by the Swiss Federal Institute of Technology in Zürich, which pictures the average First World citizen reducing their overall energy usage to no more than 2,000 Watts by the year 2050 - without lowering their standard of living (Joachim 2004). It is envisaged that achieving the aim of a 2000-Watt Society will require a complete reinvestment in the country's capital assets, including refurbishment of building stock to low energy building standards, improvements in the efficiency of the transport infrastructure, reduction in the use of energy-intensive materials, the use of renewable energy sources, district heating and micro-generation technologies. While these latest developments designed to create a way of living without fossil fuel dependency have started to impact on public consciousness, attention is now beginning to focus on the cultural consequences of a technologically driven approach to carbon reduction (Schoof 2012). A rebalancing of the effort is required, where technological advances and quantifiable metrics are matched by a more responsive humanistic approach that recognises quality of life and the inherent social, economic and cultural sustainability of places. This will require a rethinking of how and where we live and the nature and form of development and how this is integrated with energy production and consumption to produce a truly sustainable low-carbon society.

Zero Carbon Homes and Passivhaus

The two most rigorous technical approaches to low energy housing in Europe are embodied in the UK's Zero Carbon Homes (ZCH) and the Passivhaus concept. ZCH was initially based on Code for Sustainable Homes which defines the highest mandatory aspirational code for sustainable housing and Passivhaus sets arguably the most stringent energy efficiency requirements. However, their methodologies and use differ significantly. ZCH will become mandatory for all new build houses in England, Wales and Northern Ireland, needing to attain (Net) Zero Carbon by 2016 (Zero Carbon Hub 2014e). Scotland shares a similar aim with The Sullivan Report which is manifested in Section 7, Sustainability Section of the Scottish

Building Regulations (Scottish Government 2007a; Scottish Government 2012e) These standards do not primarily focus on thermal performance and do not define thermal performance levels near Passivhaus, but they provide sustainability sections for compliance including energy generation and low-carbon technology use. Both UK standards use the Standard Assessment Procedure (SAP) which is a building assessment tool designed to provide compliance with the code. However, user input is limited and the methodology relies on UK average climate data for heating requirements (BRE 2011a). Consequently, the omission of regional climate data negates the large UK regional climatic variations in the performance calculations. This means that it would be possible to pass ZCH, with a much higher heat energy demand than an equivalent PH. However, ZCH provides the ability to mitigate the increased SSHD by generating low-carbon energy from renewable technologies and through carbon off setting. It aims for housing to become a net generator of energy to the grid, balancing low-carbon energy demand and supply through renewable generation, thereby contributing to the UK's national carbon reduction requirements without adversely inflating the costs of house construction. However, this has been challenging to achieve cost effectiveness in practice. A significant difference between Passivhaus and other approaches is the use of regional climate data in heating demand simulations. The Passivhaus simulation and certification tool, PHPP, involves detailed and specific input information requiring detailed specification of building form and fabric performance. It facilitates instantaneous and simple alterations to the model once it has been established. It is recognised as a very effective design tool with transparent calculation methods, making PHPP suitable to design and simulate individual design and context specific approaches to ultra-low energy housing (Passivhaus Institut 2007). There are currently over 37,000 Passivhaus certified examples worldwide proven across many varied climates. In contrast, as of March 2012, there are only 142 CSH Zero Carbon Homes (Department for Communities and Local Government 2012). As the Scottish Government has yet to define the criteria for the anticipated Platinum Standard of the Scottish regulations, the highest regulatory standard of sustainability, there are currently no built examples to compare (Scottish Government 2012b). While the built numbers of private and commercial sector CSH compliant houses are growing slowly, the majority are expensive research prototypes. Passivhaus on the other hand has been applied in housing extensively across the world and is proven to be cost effective (~+10% premium) and in Europe this has facilitated the growth of a PH certified construction industry familiar with the more stringent construction techniques required. From the certification of the first Passivhaus in 2009, Passivhaus research in the UK has been accelerating, with approximately twenty certified built examples and a further sixty under construction (Bootland & Passivhaus Trust 2011; Zero Carbon Hub 2010b; Passipedia 2012a). However there are only six built certified examples in Scotland with the first three, namely; Tygh-Na-Cladach, Midmar by Deveci (2009), Gaia Architects (2011) and Morgan (2011) (Deveci 2011; Passivhaus Trust 2013c; Passivhaus Trust 2013a). Tygh-Na-Cladach was part of a wider development of lower specification social housing. However post occupancy evaluation demonstrated that the building did not perform as expected for various reasons (Tuohy 2011). Later examples of the Passivhaus concept have proven to be more successful such as the Dormont Estate development (S. A. H. Scottish Government 2012b). This development saw the construction of eight affordable Passivhaus for rent to the estate workers. This project was heavily subsidised by the *Rural Homes for Rent* scheme. Currently, BERE Architects generate much of the innovative research into low cost UK Passivhaus, having designed the Lime House, 2009, one

of the first affordable approaches to Passivhaus in the UK employing locally sourced materials (Bere 2013). The Larch House, 2009 , illustrates that Passivhaus can be used in conjunction with CSH using the Passivhaus fabric performance concept and methodology with the Integration of low carbon energy generation technologies to create an ultra-low energy, low cost, CSH Level 6 compliant house (Lowenstein 2011; Stothart 2010; BERE Architects 2012a). In Scotland, Porteous has investigated supply chain and costs of achieving PH in the UK, Bell has investigated suitability of PH in the UK climate, climate change and Scottish climate data. Bell and Tuohy have carried out post occupancy evaluation studies of the first Scottish Passivhaus in Dunoon (Porteous & Menon 2008; Bell 2011; Tuohy 2011). The Passivhaus approach has failed to gain wider acceptance in the UK to date with concerns raised over air quality, lifestyle changes, costs and lack of a skill base that were highlighted as factors against its adoption in the new Scottish Building Regulations (Scottish Executive 2013a). Conversely, concerns have recently been raised pointing to the potential indoor air quality issues that are predicted to occur in UK zero-carbon homes and the higher space heat demands due to the lack of MVHR. It has been argued that not adopting Passivhaus standard might not only undermine efforts to reduce energy used in Zero-Carbon homes but may create hostility from building occupants due to potentially poor environmental quality concerns (Tofield & French 2012).

1.1.5. Summary

The historic context highlights key events that have generated research into new low energy technologies, systems and houses. Globally, there are challenging legislative targets to reduce GHG emissions and pending fossil fuel shortages that require sustainable approaches. In Scotland, there are demanding targets defined in legislation regarding renewables, carbon saving and low energy buildings (ZCH). However, currently there are few examples of low energy buildings and related general research applicable to Scotland, showing there is a need for new knowledge in this area. Additionally the lack of a Scottish ZCH definition means that there are no current built examples to compare or measure. The BRE Ravenscraig development has had a slow start since its opening and does not include houses that reach a performance level near the ZCH standard or Passivhaus. Examples of Passivhaus in Scotland represent the best practice in the field of ultra-low energy housing. In general published post occupancy reports and one off research projects such as the Macro Micro studio tend to produce specific research applicable mainly to the particular building or project. Consequently, more generalised knowledge on the performance of regional ultra -low energy buildings in Scotland is required.

1.2. Thesis Organisation

This Thesis, for the first time investigates the effects of regional climatic variation in Scotland on the design of rural ULEH. It also quantifies the effect of varying orientation and formal aspects of building design on SSHD in Scotland. The variation of the formal aspects such as glazing areas and orientation, roof design and typology will determine the effect on SSHD when deviating from best practice. It uses a customized version of the PHPP as a means for assessing a best practice prototype house developed

for the study. The thesis then goes on to explore the performance of a number of exemplar house designs and implications if these were to be considered for use as ULEH. The performance of these prototypes are compared with the best practice prototype house to determine the effect of building design on heating performance. The research gives a broad understanding of the significance of regional climatic variation on the design of rural housing and determines the implications that this has on meeting Scotland's carbon reduction standards and the design of future rural housing. The results of this and the previous studies are used to develop optimised versions of the designs to establish the suitability of existing designs for use as ULEH across Scotland.

1.2.1. Thesis Aims and Objectives

This thesis seeks to add to the quantitative knowledge base for the design of ULEH in Scotland. The results of the thesis should also present a methodology for research in this area for further study.

- The primary research aim is to define the design envelope for development of more contextual and qualitative approaches to ultra-low energy, rural housing in regional Scottish climates.

In order to achieve this aim, the research will firstly demonstrate the design envelope when attempting to achieve regional solutions to ULEH in Scotland by quantifying the effects of varying key architectural parameters on the energy performance of a housing prototype across the different Scottish climatic regions. The thesis will then attempt to determine to what extent existing qualitative design exemplars can be optimised for lower space heat demands in response to the extremes of Scottish climate.

The research asks the following questions:

- How much is the SSHD likely to increase when deviating from best practice principles across a number of variables in ultra-low energy design across rural Scotland
- To what extent do different rural areas in Scotland require regional solutions in order to produce ULEH?
- Are the current ZCH specifications, approaches and analysis methodologies defined in legislation suitable to reliably produce ULEH in Scotland's rural areas?
- To what extent can existing qualitative Scottish rural housing exemplars be improved for use as ULEH in the extremes of Scottish climates through alterations of glazing and orientation?

1.2.2. Thesis Overview

The thesis is organised into nine main chapters. Due to the breadth and complex nature of the topics covered in the thesis the literature review is divided into three chapters (two, three and four). Each of these three sections cover the main drivers and examples that affect their area. Chapter two defines the Scottish rural housing context. Chapter three determines the current state of play in Scottish housing and outlines the planning system and chapter four outlines the context for the requirement of more energy efficient housing. Chapters six and seven are research projects which utilise PHPP to analyse a variety of both quantitative variables and qualitative designs to address the requirement for more qualitative design responses and quantitative energy performance. [Figure 6]

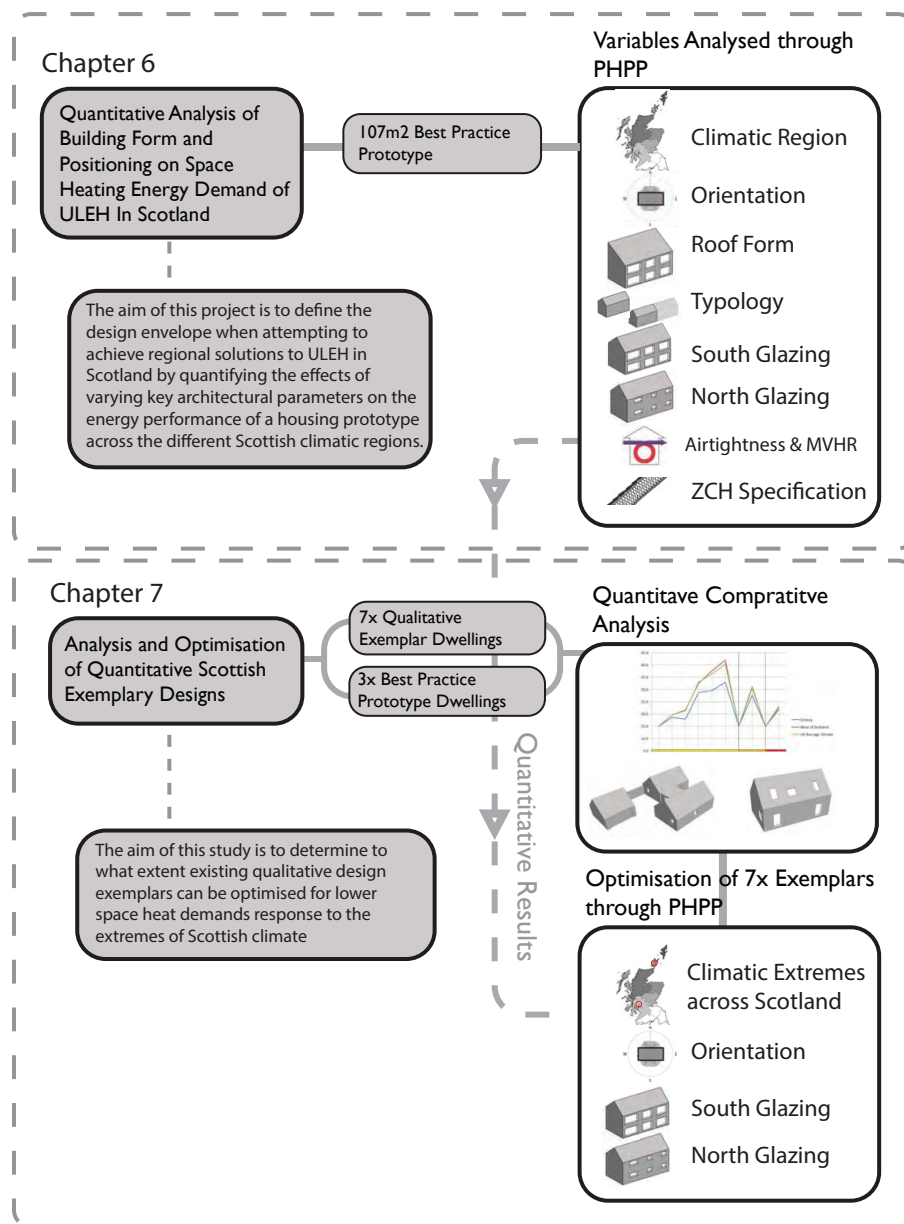


Figure 6- Research Study Structure

Chapter Outlines

1. INTRODUCTION

This chapter firstly presents a brief overview of the research field. The development of Low Energy Housing in Europe and North America is outlined to contextualise the research field. It provides the aims and objectives of the thesis with a brief summary of the thesis structure.

2. THE CONTEXT FOR RURAL HOUSING DEVELOPMENT IN SCOTLAND

The first section of this chapter contextualises rural Scotland and its important connection to landscape and traditional heritage. Rural Scottish employment and increasing population are discussed, highlighting the need for new rural development. Finally the current Scottish residential context is defined with discussions regarding; housing typologies, new housing numbers, energy use associated with housing, climatic variation and the requirement for more affordable housing.

3. SCOTTISH HOUSING CONTEXT AND PLANNING LEGISLATION

This chapter outlines the context behind the current Scottish housing context from 1930 to the present day. The current issue and possible effects of continued suburbanisation of rural areas is discussed. This then leads on to a short description of the Scottish Planning System. A detailed overview of rural guidance, legislation and initiatives are presented before a discussion on the contemporary relationship to traditional design. This section compares the approaches taken by mass market housing developers and the contrasting approaches taken by some Scottish architects.

4. DEVELOPMENT OF ULTRA-LOW ENERGY HOUSING - STRATEGIES, REGULATIONS AND SOLUTIONS

This section presents an overview of the extensive legislation governing Climate Change, Green House Gasses, renewables and building legislation. This overview covers the key drivers, regulatory requirements and targets from global issues to Scottish implications. This section then defines the Zero Carbon Homes (ZCH) context for both the UK and Scotland. The section also introduces Passivhaus and Passivhaus Planning Package (PHPP) as an alternative approach for Ultra Low Energy Housing (ULEH) in Scotland. At the end of this section there is a comparative study between ZCH and Passivhaus. Finally the section gives an overview of current Scottish low energy examples.

5. METHODOLOGY

This chapter firstly summarises the research problem, defines the research scope, aims and objectives. It then describes the rationale behind the research's use of ULEH concept Passivhaus and the use of Passivhaus Planning Package (PHPP). The principle contribution to new knowledge is outlined in relation to the requirements for knowledge and research in current practice. Finally it introduces and outlines the two research studies described in the following chapters.

6. ANALYSIS OF REGIONAL CLIMATIC VARIATION ON SPECIFIC SPACE HEAT DEMAND OF A
PROTOTYPE ULTRA-LOW ENERGY HOUSE IN SCOTLAND

This chapter describes the first of two research projects that utilise PHPP in order to determine the effect that building positioning and form have on the heating requirement. This project describes the development of a customised PHPP methodology specific to the study and the design and specification of a ultra-low energy prototype control dwelling used for the study.

7. PASSIVE SOLAR ANALYSIS AND OPTIMISATION OF QUALITATIVE SCOTTISH EXEMPLARY DESIGNS

This chapter details the qualitative designs analysis project. It develops the previous projects analysis methodology in order to determining the implications of different qualitative building designs on the heating demand. This project then determines the extent of optimisation possible on these designs in order to reduce their space heating demand to ultra-low energy levels.

8. DISCUSSION AND CONCLUSIONS

This chapter outlines the key conclusions from the research, outlining the contribution to new knowledge and applications of this knowledge in practice.

9. FUTURE WORK

The future work chapter briefly outlines possible further applications of the research. It discusses other possible projects that were considered throughout the research period. The section also discusses the relevance of the research in the authors future career in practice.

10. BIBLIOGRAPHY

The bibliography contains a list of all referenced books, journals, web pages and conference presentations.

11. APPENDIX

The appendix contains various examples of work produced through the course of the research both in practice and as part of the research.

[Figure 7] Illustrates the structure and connections between literature review chapters and study chapters.

Thesis Structure

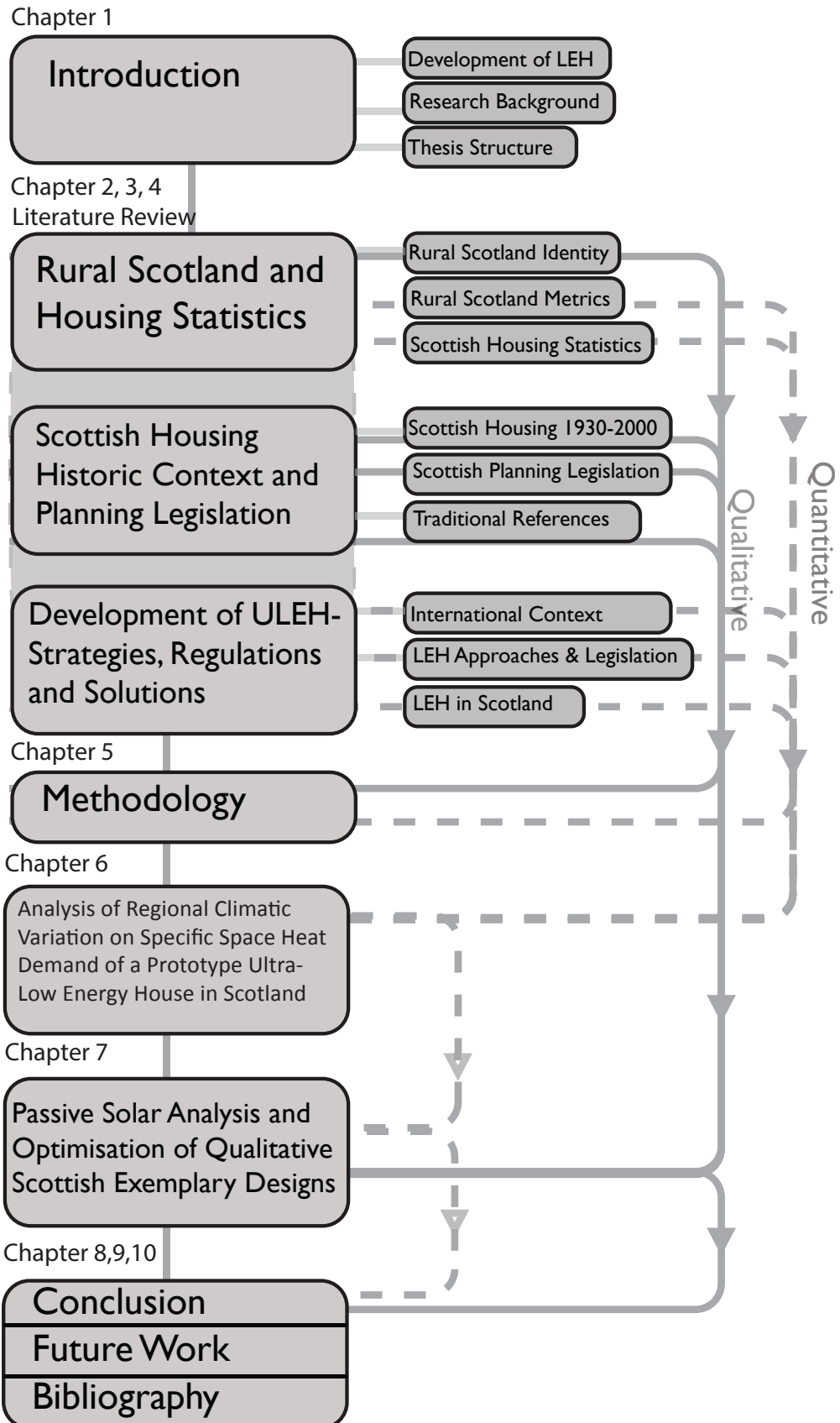


Figure 7- Chapter Structure

THE CONTEXT FOR RURAL HOUSING DEVELOPMENT IN SCOTLAND

Chapter 2



2. RURAL SCOTLAND AND HOUSING STATISTICS

This chapter investigates briefly the broad socio-political issues and statistics that affect rural Scotland and rural Scottish Housing. There are marked differences between urban and rural identities in many areas including; built environment, landscape and social identity. These differences lead to variations in population, employment, typology, energy use and energy costs. The following section contextualises rural Scotland and its regional differences in comparison to the rest of Scotland.

2.1. Rural Scottish Landscape- Identity and the Built Environment

2.1.1. Rural Scottish Landscape Identity

Scotland is renowned for its diverse range of stunning landscape which is a major draw for international tourism [Figure 8]. Much of Scotland's rural landscapes have formed through a legacy of man-made land use and development such as farming and crofting which has been a significant factor in defining the identity of contemporary rural Scotland (Architecture and Design Scotland (A+DS) 2006, p.14; Scottish Executive 2003, p.67; S. A. H. Scottish Government 2005b). Layered over generations and developed continuously since the earliest settlements, shaped by numerous complex factors, Scotland's landscapes have been developed to accommodate different types and scales of development (S. A. H. Scottish Government 2005b, p.11; Lawlor, Architecture+ Design Scotland & Scottish Government 2009; Lawlor & Skehan 2009). In recent times, the

historical past forms of small agricultural land use have been in decline for many years, with contemporary housing development having a greater lasting effect on the appearance of the landscape (S. A. H. Scottish Government 2005b). Ironically the quality of Scotland's landscape has contributed to an increasing demand for housing in the form of second homes and holiday homes. A need for the continued development in rural areas means that new sustainable strategies are needed to adapt Scotland's landscapes whilst preserving its intrinsic qualities (S. A. H. Scottish Government 2005b). Historically, regional climate and local topography have directly influenced vernacular settlement patterns and housing forms with specific regional variations evident across Scotland. In particular certain historic events have had profound effects on the built environment such as the Highland Clearances. Extensive rural settlement planning in this period took the



Figure 8- A+DS Featured Scottish Landscape (A+DS) 2006)

form of planned villages and lotted lands. Villages organised using lotted lands in which small scale farming and small scale businesses were encouraged by landowners leading to a form of self-sufficient sustainable communities (Lockhart 2001). Increasingly over the last century changes in development types, morphology and scale has had a profound effect on the sustainability and quality of the rural environment (Richards 1994). The way in which rural areas are occupied in the future will also change. The rise in tourism, the large projected increases and decreases across different areas and increasing fuel costs will require further thought to sustainable solutions (S. A. H. Scottish Government 2005b; Skerratt et al. 2012; Scottish Executive 2012i) .

2.1.2. Rural Scottish Architectural Identity

The identity of traditional Scottish architectural heritage has in part developed through hundreds of years of development of small rural houses. Arguably the traditional identity of rural Scotland's built environment is split between the primitive, indigenous 'Blackhouse' and the imported, imposed 'improved cottages' and farmhouses built between the mid-18th century and the early 20th century (Richards 1994; Maudlin 2009b). The vernacular Blackhouse, is a primitive housing type widely found in the Scottish Highlands until the mid-18th century (Richards 1994; Historic Scotland 2009a). [Figure 9] It was constructed from local materials and took its windowless form and site positioning from a relationship to natural climatic factors (Scottish Government 2005). The Highland Clearances from around 1700 to 1850 redefined the type and location of rural Scottish housing and agriculture across the highlands and islands (Maudlin 2009a). Between the 18th and 19th centuries a range of house types were introduced, these housing forms and communities are seen by many as the traditional identity of Scottish settlements (Richards 1994;



Figure 9- Blackhouse at Highland Folk Museum, Kingussie

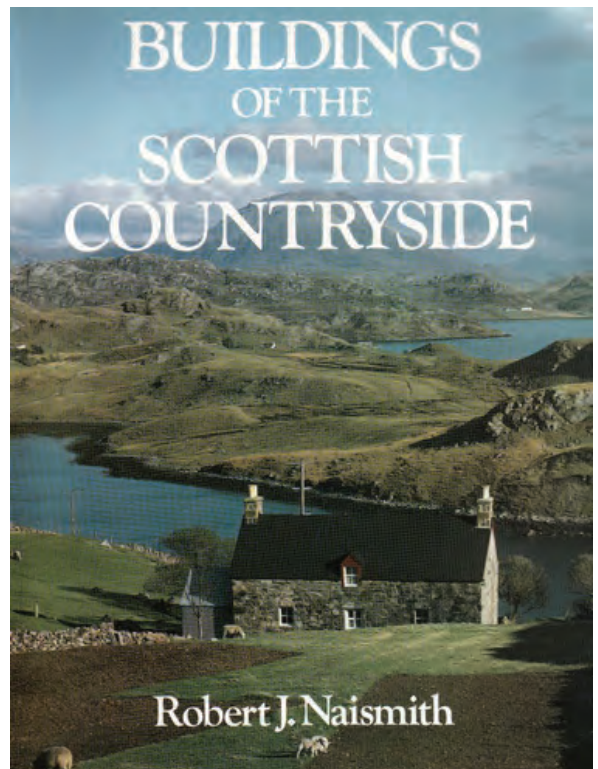


Figure 10- Improved Cottage Type



Figure 11- Traditional Detailing

Maudlin 2009b). The architect John Wood published *'Habitations of a Labourer'* in 1791 which was the first published architectural drawings and writings defining typical Scottish and English cottages based on empirical observations (Maudlin 2010; Wood 1806). These house types can be categorised into; single storey cottages, storey and a half cottage and two storey farm houses (Richards 1994; Maudlin 2009a). [Figure 10] These houses can be identified by their clear geometric form, simple composition based on



Figure 12- Falkland High Street

simple geometric ratios, stone construction, and clipped edge detailing. These features are now synonymous with the Scottish classical vernacular style (Richards 1994). [Figure 11] The traditional architecture varies across Scotland influenced by type of load-bearing stone masonry construction, local materials and local climate (Richards 1994). This often results in consistency in scale, shape, proportions, materials and colour across different regions of Scotland. In many areas, towns, villages and small settlements were comprised of clustered or aggregated typologies. This development layout created relatively dense, sheltered groupings of housing which is now seen in stark contrast to contemporary rural planning solutions [Figure 12].

2.2. Rural Scotland Definition, Population and Employment

2.2.1. Rural Scotland Definition and Population

[Figure 13]

In Scotland rural areas are defined as settlements of less than 3000 people (Scottish Executive 2010c). 94% of Scotland's land area is rural, however, rural is classified into two areas under the six fold classification system, accessible rural and remote rural (Scottish Executive 2012h). Remote rural areas are defined as being further than 30 minutes' drive from larger settlements of over 10,000 and accessible areas being within 30 minutes' drive (Scottish Government 2007b; Scottish Executive 2010c). The larger settlements of 3,000 and 10,000 are classified as towns/settlements, larger than this are classified as other or large urban areas (Scottish Executive 2012h).

Population

Estimates show that in mid-2012 the UK's population was 53.5 million with around 3.1 million in Wales, 1.8 million in Northern Ireland and 5.3 million in Scotland which is around a tenth of the total UK population (Office for National Statistics 2013a). Scotland has a similar unemployment rate to the rest of the UK at around 7.7%, but less wealthy than England with lower gross disposable income (~£ 600 less per annum per head) (Office for National Statistics 2013b).

In 2010 Scotland's total population was ~5,222,100 with 18% (~964,000) of the population living in rural areas (General Register Office for Scotland 2012; Scottish Executive 2012g). Therefore 18% of the population

of Scotland live in accessible rural and remote rural areas which account for 94% of the landmass reflecting the dispersed nature of the population in these areas (Scottish Government 2012c). Around 12% (626,519) of the Scottish population live in accessible rural areas. Rural areas with only 6% (337,470) of the population live in remote rural areas (*ibid*). Scotland's population has increased 1.7% between 2001 and 2010. In contrast during the same period the population of remote rural areas has increased by 6.2% and in accessible areas it has increased by 12.1% (Scottish Executive 2012g). Therefore Scotland's rural population is growing at a much faster rate than the rest of Scotland and is predicted to grow 10% by 2035 (Skerratt et al. 2012). While the rural population is growing, this is not distributed equally across all local authority regions. The range is from a 32% increase in Perth

and Kinross to a 11% decline in Eilean Siar (Western Isles Council). The recent and projected increases in Scotland's population, with larger proportional increases in rural areas suggest the requirement for more new rural homes. To address the requirement for more housing local planning authorities have developed long term strategic development plans such as the Tay Plan - the Strategic Development Plan for Dundee, Angus, Perth and North Fife (Ewen et al. 2013). These areas include both accessible rural areas and some remote rural areas. The results of an extensive consultation has produced an approach that generally concentrates the majority of the region's new development within its principle settlements of Perth and Dundee rather than smaller scale development across rural areas (Ewen et al. 2012). This long term strategic approach compounds the lack of rural housing suitable for rural workers. The increases in population will in turn inflate prices of existing rural homes making it harder for rural workers to live in rural areas with higher rents/ mortgages and potentially lead to greater instances of fuel poverty due to the exponentially higher costs of fuel in remote rural areas (Scottish Executive 2012g).

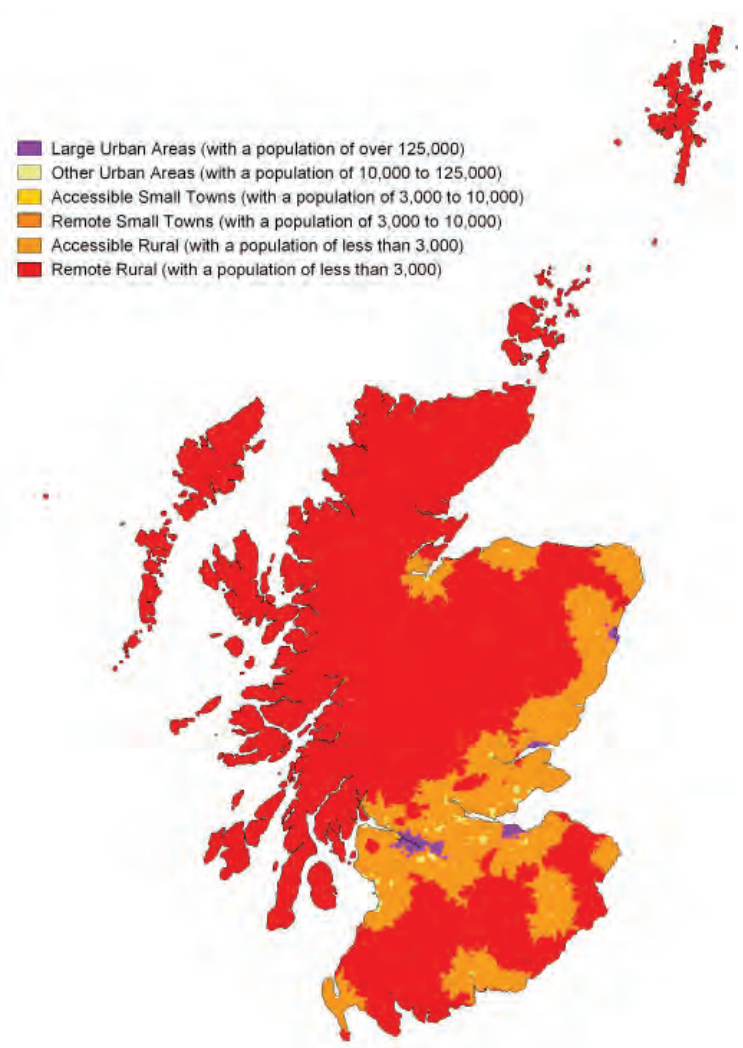


Figure 13 -Rural areas classification (Scottish Executive 2012h)

Age Groups

From the 2001 census, rural areas have a different distribution of ages to urban areas, with a lower percentage of young adults (16-34) and a higher proportion of over 45s. Only 17% of the population of remote rural areas are young adults (16-34) compared to 19% in accessible rural areas and 26% for the rest of Scotland. Over half (53%) of the remote rural population are aged over 45 in comparison to accessible rural areas (47%) and the rest of Scotland (42%) (Scottish Executive 2008a).

Climatic Variation

Due to Scotland's wide range of latitude, complex geography and extensive coastline, there is significant climatic variation across its regions. The climatic variation across rural areas is greater than urban areas due to locations and spread of the four major large urban areas relative to the large number of rural small settlements spread across Scotland. However, it is difficult to quantify the difference in climate of urban centres and rural areas due to the complex nature of the micro climates and categorisation of climate data. There are significant regional differences in climate across rural Scotland, with complex weather patterns affected by factors such as; the maritime influence, the warm Gulf Stream affecting the west coast, a latitude range from 54.98° north to 60.38° north, complex, mountainous topography. Also many areas can have very high average wind speeds and high rainfall caused by micro climates. Historically, this has led to a rich and diverse architectural tradition that varies with region, landscape and climate and as a result a major part of Scotland's identity is vested in its natural and built rural landscapes (Burford & Pearson 2013).

The detailed meteorological information for key Scottish climatic areas will be developed in detail in Section 4.3.

2.2.2. Rural Employment & Commuting

In some cases the urban and rural divide is being blurred with significant numbers of the occupants commuting from rural areas into urban areas. The 2005 Planning Advice Note; Housing in the Countryside (PAN 72) highlights the rise in the number of people wishing to live in the accessible parts of the countryside who work in towns and cities and others who wish to live and work in the countryside (S. A. H. Scottish Government 2005b). These changing trends in demographics are considered to be due to lifestyle choices and technological advances such as the internet that allows for home working. The majority of the remote rural population work in remote areas with only 5% working in accessible areas and 27% working in other areas in Scotland (Scottish Executive 2012g, p.26). 'Employment in remote rural areas in particular is reliant on the agriculture sector and constitutes more small and medium-sized businesses than in the rest of Scotland' (Scottish Executive 2012g, p.3). In rural areas a greater proportion of workers are likely to be small employers or own account workers with 21% in remote areas, 14% in accessible areas compared with 7% in the rest of Scotland (Scottish Executive 2012g, p.43). In remote rural areas, a higher percentage of people are employed within the 'Agriculture, forestry and fishing' and 'Accommodation and food services' sectors (Scottish Executive 2012g, p.40). The 52% of the accessible rural population work in areas outwith rural areas with only 46% working in accessible rural areas (*ibid*). The spread of employment in Accessible rural tends to be similar into that of Remote rural areas and the rest of Scotland however, the 'Manufacturing'

sector tends to be slightly more prevalent in accessible areas (*ibid*). In accessible rural Scotland 64% of the residents spend over £100 a month on fuel for cars, compared to 48% in the rest of Scotland in 2011 (Scottish Executive 2012g, p.3). These figures illustrate a high level of commuting from rural areas to small towns and cities across Scotland. This could be attributed to the perceived higher quality of life as rural areas have been shown to have a higher rate of neighbourhood satisfaction (Scottish Government 2011f; Scottish Executive 2012g).

2.3. Scottish Housing Statistics

2.3.1. Housing typologies, Age and Use in Scotland

Typologies

Since the early 1980's, detached houses have dominated the new-build market in Scotland (Scottish Executive 2013c, p.117). As a whole a large proportion of pre 1919 dwellings were tenements, and semi-detached and terraced house typologies built predominantly between 1945 and 1982, located mainly in the larger urban areas such as Aberdeen, Dundee, Edinburgh and Glasgow (Scottish Executive 2012e, p.10). Consequently, current Scottish urban housing stock is comprised of a high proportion of flatted development whereas the rural housing stock comprises predominantly of detached typologies. In 2011, housing in Scotland's large urban areas consisted of a large proportion of flats/maisonettes which constituted 39% of the housing stock, 21% semi-detached and the remainder detached properties (Scottish Executive 2012g, p.32)]. Detached house types make up the majority of housing types in remote (58%) and accessible rural areas (48%). Both areas share the same percentage of semi-detached housing typologies at 24% (*ibid*)[Figure 14]. Both detached and semi-detached housing which generally have larger exposed surface areas compared to terraces and flats flats, and generally detached houses have the highest level of CO₂ emissions and tenements the lowest due to the increased area of exposed sides, a less efficient form factor as heat losses are greatest from detached housing (Scottish Executive 2012g, p.32).

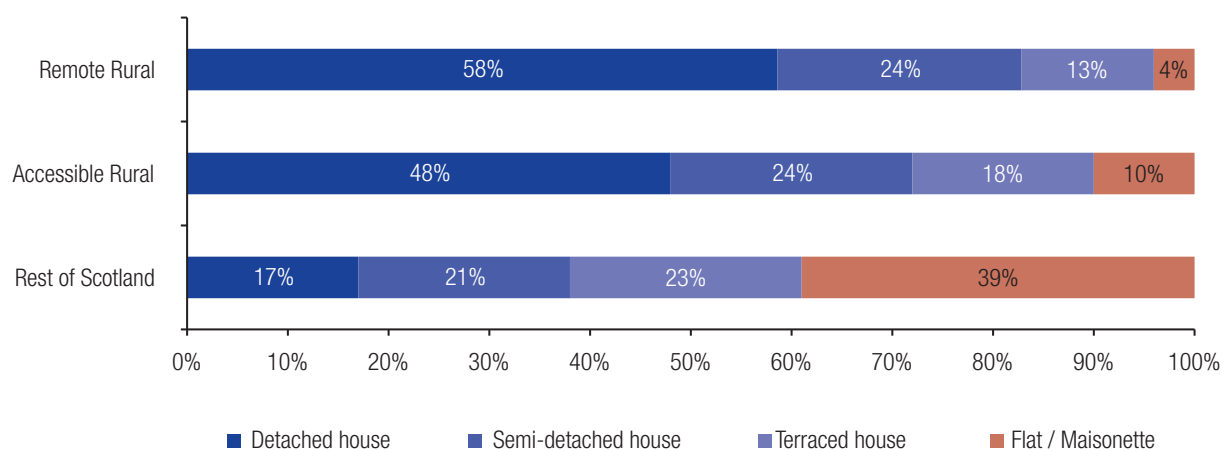


Figure 14- Property Type by Geographic Areas, 2011 (Scottish Executive 2012g, p.32)

Age

The age of the housing stock is also a factor in current and future energy efficiency. Older housing tends to have higher carbon emissions and is more difficult to insulate due to non-cavity wall constructions (Scottish Executive 2012e). There are significant numbers of older detached housing particularly in rural areas (Scottish Executive 2012g, p.32)). A fifth of Scottish homes are now over 90 years old, and a third more than 67 years old and a further fifth of the Scottish housing stock has been built within the last 30 years (Scottish Executive 2012e)(Scottish Executive 2013c) . In mid-2011, there were around 2.37 million households in Scotland, occupying 85% of the housing stock expected still to be in use in 2050 (Scottish Executive 2013c). The Scottish Government is currently attempting to address this with a number of energy improvement schemes to improve the energy efficiency of existing the housing stock.

Second Houses

Remote rural areas have the highest percentage of second or holiday homes with over 7% of the total housing stock compared with large urban areas, around 1% (National Records Of Scotland 2011). The Housing in the Countryside (PAN 72) document states the increase in people buying second or holiday homes in rural Scotland in addition to an increase in the popularity of timeshare and chalet developments (S. A. H. Scottish Government 2005b, p.72). In many rural areas nearly 50% of housing stock is second homes and vacant property, significantly effecting the availability and cost of housing in rural areas and additionally the resilience and sustainability of rural economies (Skerratt et al. 2012). Statistics from Census 2001 show that people living in accessible small towns (63%) and accessible rural areas (54%) were most likely to commute out of their area compared to large urban areas (12%) (S. A. H. Scottish Government 2005a). People in accessible rural areas are most likely to commute to work in urban areas. Commuters from accessible rural areas were the most likely to have to travel over 5km to their place of work or study (60%) (*ibid*). Commuters travelling out of remote rural areas are most likely to work in remote small towns. Commuters from remote small towns were the least likely to have to travel over 5km (28%) (*ibid*).

2.3.2. New Housing Numbers in Scotland

It was stated by UK government in 2007 *“that in the UK a total of three million new homes were to be built by 2020, two million of them by 2016”* (Communities and Local Government 2007). The National Records of Scotland forecast that 450,000 extra homes will be needed in Scotland by 2033 (Scottish Government 2012a). The period between 1952 and 1977 signified a house building boom in Scotland, and throughout this period the annual numbers of completions did not fall below 26,000 with a peak of 43,126 in 1970 (Scottish Executive 2012d). In the last 30 years the peak of new house building in Scotland was in 2007 with 25,741 new houses constructed (*ibid*). From a peak in 2007, the new build figure has been steadily reducing to the present day with only 14,881 constructed in 2012 (Scottish Executive 2013b). Of this, almost 10,000 were private new builds, with 3,200 being constructed by Housing Associations and the remainder built by local authorities (Scottish Executive 2012d). Over the next two decades the number of households could increase by more than 20% which equates to an average of 19,250 extra households each year (Scottish Executive 2012e). Projections show that there will be a significant reduction in the need for large detached houses

and a greater requirement for smaller, households suitable for the aged, with lower running costs, access to services and transport links (*ibid*). Over recent years, the population of rural Scotland has continued to grow at a faster rate than its urban centres mainly due to inward migrants moving from urban areas (53%) or from another parts of the UK (20%) (S. A. H. Scottish Government 2005a). The predicted rise in Scotland's population could require up to 500,000 new houses by 2035. However, this is spread unevenly across local authorities, ranging from approximately one third increase of population in Perth and Kinross to a 11% decline in Eilean Siar (Western Isles Council) (Skerratt et al. 2012). Therefore, a significant proportion of new houses are required in some rural environments in small Scottish towns and villages. However, the rising requirement for new rural mass market housing is to be provided within accessible rural rather than remote areas due to the significant number of householders commuting from rural areas in to the larger urban centres and householders working from home (Sustainable Development Commission & Dwelly 2009). Consequently there is a lack of appropriate affordable housing across Scotland but particularly in rural areas where the average price is higher than the average across the UK (BBC 2009). Second or holiday homes have become more popular through the developing leisure and tourism market (National Records Of Scotland 2011; Burford & Pearson 2013). Remote rural areas are comprised of 7.4% second or holiday homes contributing to inflated prices which affects residents ability to access affordable housing (S. A. H. Scottish Government 2005b; Skerratt et al. 2012; National Records Of Scotland 2011). In addition in remote rural areas, 4.6% of homes are vacant, contributing to the lack of housing (Skerratt et al. 2012). For comparison, the combined average of second and vacant homes across Scotland is 4.2% (SRUC 2013). Traditionally larger rural settlements close to larger urbanised centres have grown and developed as commuter settlements. However, the range of possible development sites appears to be expanding to settlements further from urban areas.

Current figures of new build dwellings across the UK are significantly lower since the financial crisis in 2008. If the rising population follows the projections, the requirement for new housing in rural areas will become an even greater challenge. House Prices during the financial crisis plummeted with an over 17% fall in the average house price in 2008 from a high of around +10% in late 2007 (BBC 2013). The average price of a home in the UK peaked in late 2007, plunging rapidly in 2008 before almost recovering in 2009, 2010 and 2011 stabilised at around 0-3%. Currently, in 2013 the house prices are at a high of around +5.5% (BBC 2013). Over the last 10 years the average Scottish house price has increased 73% at £179,067 (Scottish Executive 2013b; Shelter Scotland 2013). It was found in a recent study that house prices in areas desirable for holiday and second homes were higher than in other areas, with 47% of second homes in remote rural areas (Communities Scotland & Throp 2005).

2.3.3. Energy Use and Fuel Poverty in Rural Scotland

CO₂ Emissions in Scottish Housing

The domestic sector accounts for more than a quarter of all Scotland's carbon emissions and nearly a third of its energy use (Scottish Executive 2012e). In 2009, nearly two-thirds of domestic energy was used for space

heating and a further 18 per cent of energy was used for water heating (*ibid*). Research performed in 2011 explored the Scottish domestic average CO₂ emissions between 2003 -2010. The findings revealed significant reductions in domestic energy use since 2007 with the lowest CO₂ emissions in 2010 (13.1 million tonnes CO₂/ year) (Scottish Executive 2011b, p.25). This figure has reduced from a high of 16.3 in 2004/5 (*ibid*). The research also illustrates that Scottish detached dwellings have significantly higher CO₂ emissions than any other housing typology. In 2010 the average detached house consumed 8.5 tonnes CO₂/a, compared with, semi-detached: 5.8 tonnes CO₂/a. Tenements consumed less than half of a detached dwelling with 4 tonnes CO₂/a (*ibid*). The total average CO₂ emission from dwellings in 2010 was 13.1 tonnes CO₂(*ibid*). Due to rural areas having a greater share of detached houses the per capita domestic CO₂ emissions are higher in rural local authorities (Highlands, Western Isles, Shetland, Orkney, Borders, Dumfries and Galloway, Aberdeenshire) (Skerratt et al. 2012; Scottish Executive 2012g, p.32)]. This figure can also be attributed to the poorer energy efficiency ratings of rural domestic properties.[Figure 15] (Skerratt et al. 2012; Scottish Executive 2012g).

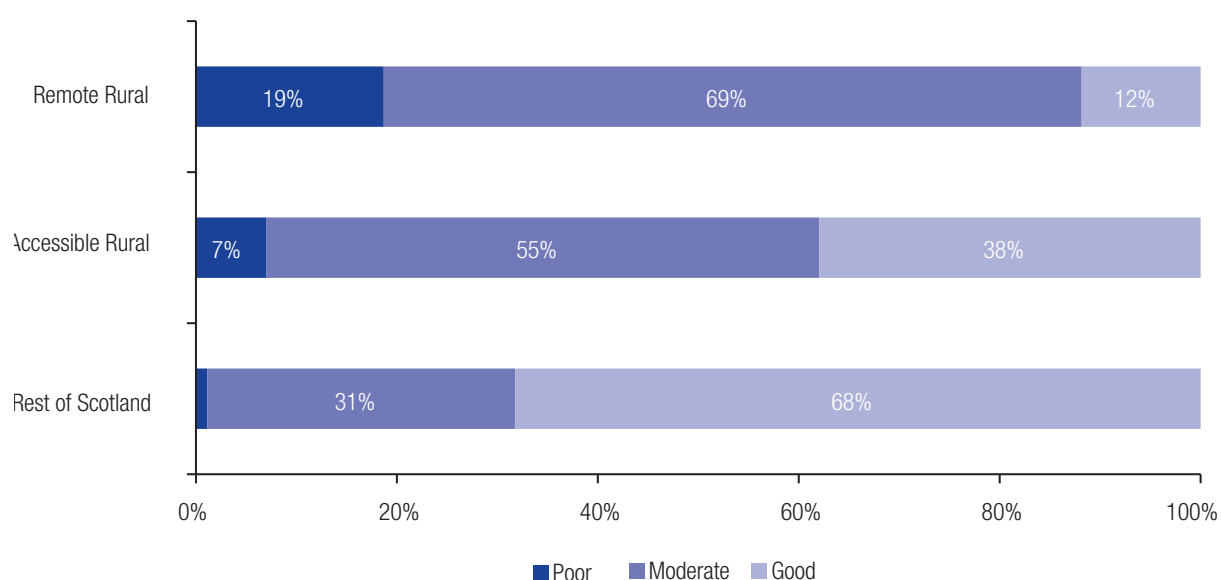


Figure 15- Energy Efficiency by Geographic Areas, 2011 (Scottish Executive 2012g, p.36)

Fuel Use and Fuel Poverty in Rural Areas

The Scottish Executive stated that “households living in dwellings not on the gas grid are twice as likely to be in extreme fuel poverty as those who are on the gas grid” (Scottish Executive 2011b). In Scotland 99% of urban dwellings are connected to the gas grid with only 54% in rural areas (Scottish Executive 2011b, p.11). Around 92% of Scottish dwellings not connected to gas supplies are in rural areas (Skerratt et al. 2012; Scottish Executive 2012e; Scottish Executive 2011b). Therefore the average domestic electrical consumption for accessible and remote rural is much higher (11100-12300 kWh per annum) in comparison with urban areas (8600- 9500 kWh) (*ibid*). A representative energy consumption comparison across all fuel types is difficult due to the numbers of rural dwellings that are ‘off-grid’ being heated by wood, peat or oil rather than through the national gas grid (*ibid*). Due to the large number of ‘off gas grid’ domestic properties in

rural areas there are greater potential benefits to adopt district heat/power schemes, low carbon renewable heat sources and renewables. However, costs and infrastructural challenges such as connectivity to the grid must be recognised as a major challenges to overcome in making fuel running costs in rural areas equitable to urban areas.

Scottish Homes Energy Rating

Studies using SAP have shown the cost of heating to be higher in rural areas due to energy performance of homes (Scottish Executive 2011b). Rural areas have a mean Standard Assessment Procedure (SAP) 2005 rating of 52.3 while urban areas the mean is 63.8 (*ibid*). The SAP rating is a fuel-cost-based energy efficiency rating (100 being cheapest). However, because SAP methodology does not take climate into account the actual differences between home heating costs in different climatic regions is likely to be significantly greater than has been reported to date. SAP will be explained in detail in Section 4.3.1.1. Evidence from studies using the National Home Energy Rating (NHER) corroborates this finding with urban and rural domestic properties having poorer energy efficiency ratings when using this alternative assessment methodology (Skerratt et al. 2012). NHER works similarly to SAP but considers regional variation, appliance & cooking energy use, occupancy and detailed heating use information and generates a rating between 0 and 10 based on the total energy costs per square metre of floor area (National Energy Services 2010). In 2010, 11% of rural dwellings in Scotland were rated as poor in comparison to only 1% of urban dwellings. At the same time, 68% of urban dwellings were rated as good in comparison to only 29% of rural dwellings (Skerratt et al. 2012). The average urban NHER rating was 7 and the rural rating was 5.1 (*ibid*).

Fuel Cost and Fuel Poverty

Scottish household energy costs rose by 76% in real terms between 2000 and 2010 (Scottish Government 2012a). The increase in electricity and gas unit price since around 2008 has led to a consequent increase in the numbers of households in fuel poverty across the UK which is particularly evident in rural areas (BBC 2012b). Additionally the base cost of energy in rural Scotland is higher compared to the rest of Scotland due to transport costs and the lack of availability of services. Due to the lack of gas connection in some rural areas many houses are forced to rely on heating oil and electricity which drive up the running costs for heating and cooking due the difference in energy unit prices between fuels which contributes to the increasing the number of people in fuel poverty(Scottish Executive 2011b). The definition of fuel poverty is if, in order to maintain a satisfactory heating regime, the household would be required to spend more than 10 per cent of their household income (including Housing Benefit or Income Support for Mortgage Interest) on all household fuel use(Scottish Executive 2008f; Boardman 1991). *“Fuel poverty is a recognised social problem that affects the poor and is a result of the quality of housing and cost of fuel”* (Scottish Executive 2012i). *‘The Scottish Fuel Poverty Statement’* declared in 2002 that the government aims to eradicate fuel poverty as far as reasonably practicable by 2016 (Scottish Executive 2002; Scottish Executive 2012i).

However, fuel poverty has been rising in more recent years, largely because current increases in fuel prices are only being partially offset by rising incomes and energy efficiency increases. In Scotland, 2010, 28% of households were in fuel poverty, compared to 13% in 2002. (Scottish Executive 2012f). Fuel poverty is also worse in Scottish rural areas with 38% of the rural population suffering from fuel poverty compared with 26% in urban areas (Scottish Executive 2012i). [Figure 16]

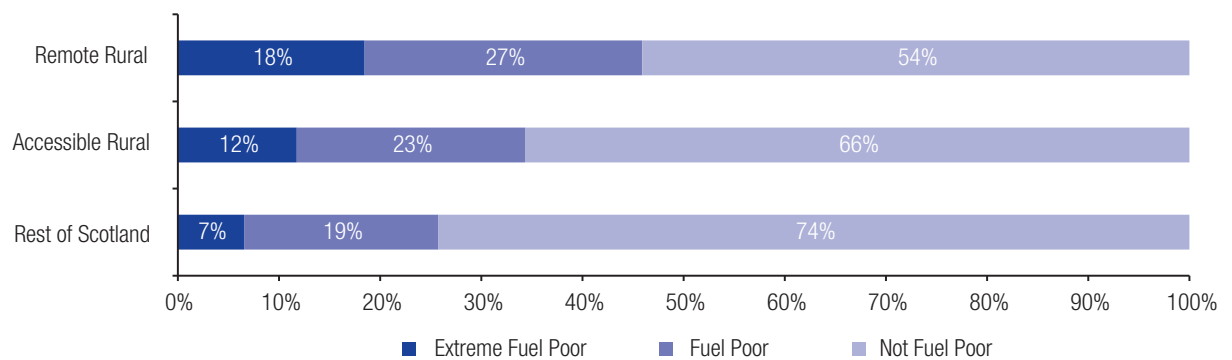


Figure 16- Fuel Poverty by Geographic Areas, 2011 (Scottish Executive 2012g, p.37)

A number of factors influence the fuel poverty specifically in rural Scotland, including (Scottish Executive 2012i):

- High Proportion of detached housing types- proven to have higher heat losses
- Age and Construction of Houses- more likely to have solid walls and as a result poorer U-values
- Extreme weather conditions -Orkney Isles and the Western Isles experience the highest levels of fuel poverty, Central Belt has the lowest levels of fuel poverty
- High Fuel costs - Rural houses are more likely to be off mains gas grid and consequently do not have access to cheaper fuels

The Scottish Executive published the '*Fuel Poverty Evidence Review*' which highlights the remoteness of rural Scotland, stating that the remoteness is often paired with unreliable electricity supply methods. In Orkney, nearly half of households are fuel poor, which can be mainly attributed to the harsh climate, high fuel costs and low incomes (Scottish Executive 2012i; Inkster 2010).

'*Fuel Poverty Evidence Review*' determines that: In Scotland, the rural fuel poor households are (Scottish Executive 2012i):

- *"Five times more likely to be single pensioners (31% compared to 6%) and twice as likely to be households with more than one elderly person"*
- *"Over three times more likely to live in a house with a poor NHER rating (21% compared to 6%) and far less likely to live in one with a good rating"*
- *"Twice as likely to live in older homes (built pre-1919) (41% are fuel poor compared to 24% non-fuel-poor) "*

- *"Twice as likely to own their own homes outright (56% compared to 23%)"*
- *"More likely to be off grid (61% compared to 45%)"*
- *"More likely to live in a detached house (58% compared to 42%)"*

The proportion of households in rural Scotland which are classed as extreme fuel poor (EFP) (more than 20% of income on household fuel) is 38%, approximately double the rest of Scotland (17%) (Scottish Government 2011f, p.3) (Scottish Executive 2012i). In Scotland, 36% of the EFP live in a detached houses compared to 19% non-EFP and 21% of the Scottish population (Scottish Executive 2012i)

2.3.4. Climatic Variation across Scotland

The climatic conditions where a building is located has a significant effect on building heating and cooling performance in order to maintain a comfortable temperature. While Scotland has a comparatively small land mass there are significant regional differences in climate. Unlike central Europe, Scotland tends to have significantly more complex weather affected by factors such as; the maritime influence, the warm Gulf Stream affecting the west coast, a latitude range from 54.98° north to 60.38° north, complex, mountainous topography,

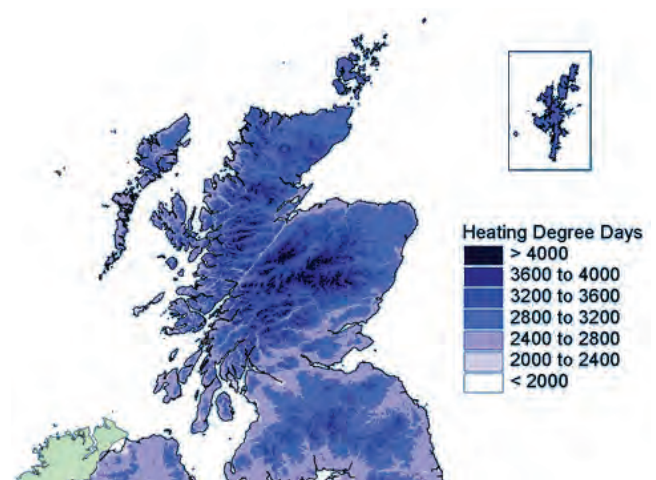


Figure 17- Degree Heating Days (Met Office 2013f)

very high average wind speeds and high rainfall. The UK Met Office produce average weather information. These figures illustrate a significant variation across the three defined regional Scottish climates. The average figures are a mean average taken from 1971 to 2000. The Met Office also define major geographic features that have a significant effect on the average weather in the regions. The northern Scottish climate is effected by large expanses of high ground and complex coastline. This region has the harshest climate in Scotland (Met Office 2013c). The regional climate has major variations due to variations in topography and proximity to the coast. Western Scotland is effected by the gulf stream which brings a greater variation between higher and lower average temperatures (Met Office 2013d). The west is also a wetter climate when compared with the East. The East of Scotland is defined by its the valleys and estuaries. The east of Scotland is sheltered from the prevailing Westerly wind, and is the driest, sunniest climate (Met Office 2013b. These locational and geographic variations cause significant regional variations. The most influential climatic information for low SSHD is the average temperatures and solar isolation. Scotland's lowest mean annual temperature is 0°C on Ben Nevis in the North of Scotland. The highest mean annual temperature is in the west of Scotland at between 9.4 and 9.7 °C in Glasgow and Ayrshire, Bute and Kintyre. The highest annual sunshine hours is on the Fife coast with over 1500 hours with the lowest at less than 1100 hours on the Grampian mountains. A key metric of temperature analysis of a climate is the Heating Degree Days. Heating degree days are

measured relative to 15.5°C. The average number of degrees required to meet 15.5°C per house are counted and averaged over the number of days for the calculation. The variation in degree days is approximately 2400-2800 in low lying coastal regions to over 4000 in higher mountainous areas in the north (Met Office 2013f)[Figure 17]. This will roughly correspond to the required use of heating in a standard home, not taking into account solar gains. This varied range of geography, climatic extremes illustrate the requirement for more regional solutions to ultra-low energy design.

2.3.5. Affordable Rural Housing

In 2005 there was a stated shortage of affordable housing in many areas of rural Scotland documented in the Planning Advice Note (PAN 74), a document that aimed to focus on the provision of new Affordable Housing (Scottish Executive 2005). The Scottish Planning Policy states the definition of affordable housing as: *“housing of a reasonable quality that is affordable to people on modest incomes... affordable housing may be in the form of social rented accommodation, mid-market rented accommodation, shared ownership, shared equity, discounted low cost housing for sale including plots for self-build, and low-cost housing without subsidy”* (Scottish Government 2010c, p.22).

The reasons for the lack of affordable housing in rural area include (Scottish Executive 2005, p.2):

- *Stocks of social rented, privately rented and cheaper owner occupied houses may be relatively scarce,*
- *A low turnover of social rented housing*
- *Some rural settlements are desirable locations for commuters and their families*
- *Some rural settlements are popular with second home and holiday let purchases*
- *Not enough houses of the right type are being built*

There is likely to be a short fall in *‘affordable housing to meet the needs of new households who wish to remain in the area and contribute to the local economy’*(Scottish Executive 2005, p.2). In 2009 rural house prices in Scotland fell less than urban areas causing housing to be *‘significantly less affordable than in urban areas,’* pricing some rural workers out of the buyers’ market. This is aggravated by the relatively low levels of social housing (BBC 2009; BBC 2011a). Recent reports state that the affordability of rural homes in Scotland as one of the best in the UK and could be attributed to low land values as compared to urban areas (McKay 2013). However, the condition and location is not considered nor the requirement for affordable rural housing suitable for rural workers on lower salaries (*ibid*). Rural properties generally have a price premium over urban homes. In Scotland this premium is 17%, with the average rural house costing £160,374, compared to £137,352 average in urban areas. Orkney has one of the smallest percentages of properties meeting criteria for social housing in Scotland with 8%, while East Ayrshire has the highest with 22% (Scotsman 2013; Lloyds 2013).

Currently there is still a lack of affordable housing despite various grants and pilot schemes (Royal Institution of Chartered Surveyors 2011; Brotchie 2013; SRUC 2013). The lack of affordable housing is regarded as one of

the most significant challenges facing rural Scotland.

A meeting in 2012 outlined some of the current issues regarding the lack of affordable housing:

- Severe shortage of suitable affordable housing
- Rural Scotland's out of proportion increasing population
- Ageing population will require more, smaller adaptable homes.
- Low wages, more than half of the higher remote rural salaries are under £20,000 in 2011
- Lack of long term rentable properties
- The number of people in fuel poverty is disproportionately large in rural areas.
- The number of second or holiday homes in remote rural area make up 12% of the available housing stock compared to the Scottish average of 4.2% (Skerratt et al. 2012).
- Rural areas with high average house prices which are likely to increase with growing populations (Perth and Kinross, Aberdeenshire, the Lothian's and the Borders)

Currently various stakeholders are addressing the lack of affordable rural housing such as the Rural Housing Service and Highlands Small Communities Housing Trust and Dumfries and Galloway Small Communities Housing Trust and Scottish Empty Homes Partnership (SRUC 2013). The RHS work towards providing more affordable rural housing, their activities include holding conferences, producing guides and running architectural design competition 'Our island Home' in 2013 to provide affordable housing models for areas of the Scottish islands (Rural Housing Service 2013b; Rural Housing Service 2013a). A significant development that involved new funding mechanisms and ultra-low energy concepts to achieve affordable housing is the Dormont Estate Passivhaus development. The development of eight Passivhaus affordable homes on the Dormont Estate in 2011 by White Hill Design Studio is designed specifically as social housing with extremely low running cost developed through the Scottish Governments Rural Homes for Rent pilot scheme (Passivhaus Trust 2013b; Scottish Executive 2008e). This is an exemplar project that pointed to a possible alternative approach to thinking about housing provision holistically tackling the various multivalent issues that affect housing affordability. However, the government Rural Homes for Rent scheme was retracted after the construction of these affordable homes (Scottish Executive 2008e; Scottish Land and Estates 2011). The Dormont Estate project is discussed in more detail in section 4.4. Scottish Government funds rural regeneration projects however, initiatives generally apply to settlements (small towns) with populations between 3,000 and 10,000. As a result many remote small towns are more vulnerable than their rural hinterlands with less opportunities for funding, especially in accessible rural areas (Skerratt et al. 2012).

2.4.Scottish Rural Housing Context Summary

Extremely high proportion of Scotland's land area is rural (94%), but a small proportion of the population inhabit the area (18%) (Scottish Executive 2010a; Scottish Executive 2012g). Scotland is famous for its rural landscapes that have developed over years of mainly agricultural development. The traditional identity of Scottish residential architecture can be associated with rural cottages and workers houses. Rural Scotland is sometimes overlooked due to the relatively small population which is particularly evident in remote rural areas. The average rural home tends to be older, of a poorer standard, less efficient typology (detached) with less connection to cheaper grid fuels than its urban counterpart. The high proportion of second\ holiday homes combined with increasing home-workers and commuters is leading to a shortage of affordable homes for rural workers. Around 38% rural households are living in fuel poverty (Scottish Executive 2012i). This can partly be attributed to factors effecting rural dwellings. There are numerous contributing factors in rural areas, these include; harsher than UK average climate, the dependency on costly off grid fuel sources and a high proportion of detached dwellings with poor energy efficiency ratings which leads to increased space heating energy use. The climatic variation across Scotland is significant, particularly in rural areas, due to a number of climatic factors (Scottish Executive 2012i; Inkster 2010). Due to this many homes within the Scottish regions will require significantly more energy for space heating than the UK average. In particular the islands have more demanding climates therefore space heating will be higher than other areas in Scotland. This is reflected in statistics for Orkney that state almost 50% of the population are affected by fuel poverty compounded by the low availability of social housing at 8% (Scotsman 2013; Lloyds 2013) (Scottish Executive 2012i; Inkster 2010; Scotsman 2013; Lloyds 2013). This variation in space heating demand can be difficult to identify through UK energy use and CO₂ emission data as 46% of rural homes are not connected to the gas grid and rely on unmetered fuel sources such as peat, timber, oil and tanked gas (Scottish Executive 2011b, p.11). In addition to the requirement of affordable, fuel efficient homes, the Scottish population is due to increase by around 10% by 2035, in some rural areas 32% is predicted (Skerratt et al. 2012). The large increase in population will require significant numbers of new houses to be built, which if current trends and development patterns prevail will have a significant effect on the landscape. Therefore there is a need for the development of suitable, sustainable rural residential development that addresses the affordability and energy usage requirements of the rural population.

SCOTTISH HOUSING CONTEXT AND PLANNING LEGISLATION

Chapter 3



Building Scotland (Reiach & Hurd 1941)



Dualchas House, Harris

3. SCOTTISH HOUSING HISTORIC CONTEXT AND PLANNING LEGISLATION

The following chapter provides a brief historical context for Scottish rural housing from 1930 to current day. It then discusses the current Scottish Planning and Design guidance as it relates to current rural housing practices.

3.1.Scottish Housing Historic Context 1930 to 2000

The following section discusses the historical developments in rural Scottish housing over the last century and the simultaneous influence and changes in planning legislation.

3.1.1. Context Summary

[Figure 18]

In the 1930s industrialisation, urbanisation and economic crisis led to very poor working class housing standards. By late 1930's in an attempt to redress this the Special (Areas) Housing Association (SHA) had implemented policies around Garden City principles which favoured groupings of semi-detached cottages in English arts and crafts style (Lewis 2007). During the 1940s the public sector accounted for 90% of new build houses (*ibid*). Typical tenement dwelling typologies were considered to be backward overcrowded slums with changes in planning policies leading to the introduction of modern continental flatted development. This was encouraged in 'Building Scotland: A Cautionary Guide' published in 1941 by the Saltire Society (Reiach & Hurd 1941).[Figure 19] Much of the urban architecture in the mid-20th century aimed to ease the



Figure 18 Excerpts from Building Scotland (Reiach & Hurd 1941)

housing shortages and improve the quality of housing by implementing utopian modernist ideas (Glendinning & MacKechnie 2004; Lewis 2007). The New Towns Act 1946 led to the largest Scottish developments in this period which led to the eventual construction of five Scottish new towns; Cumbernauld, East Kilbride, Glenrothes, Irvine and Livingston (Reith 1946; Central Office of Information 1968). Public sector housing accounted for 91% of new house builds during the 1950's with early modernist architects such as Morris Steedman, Matthew and Spence favouring the use of traditional materials and reinterpretation of traditional

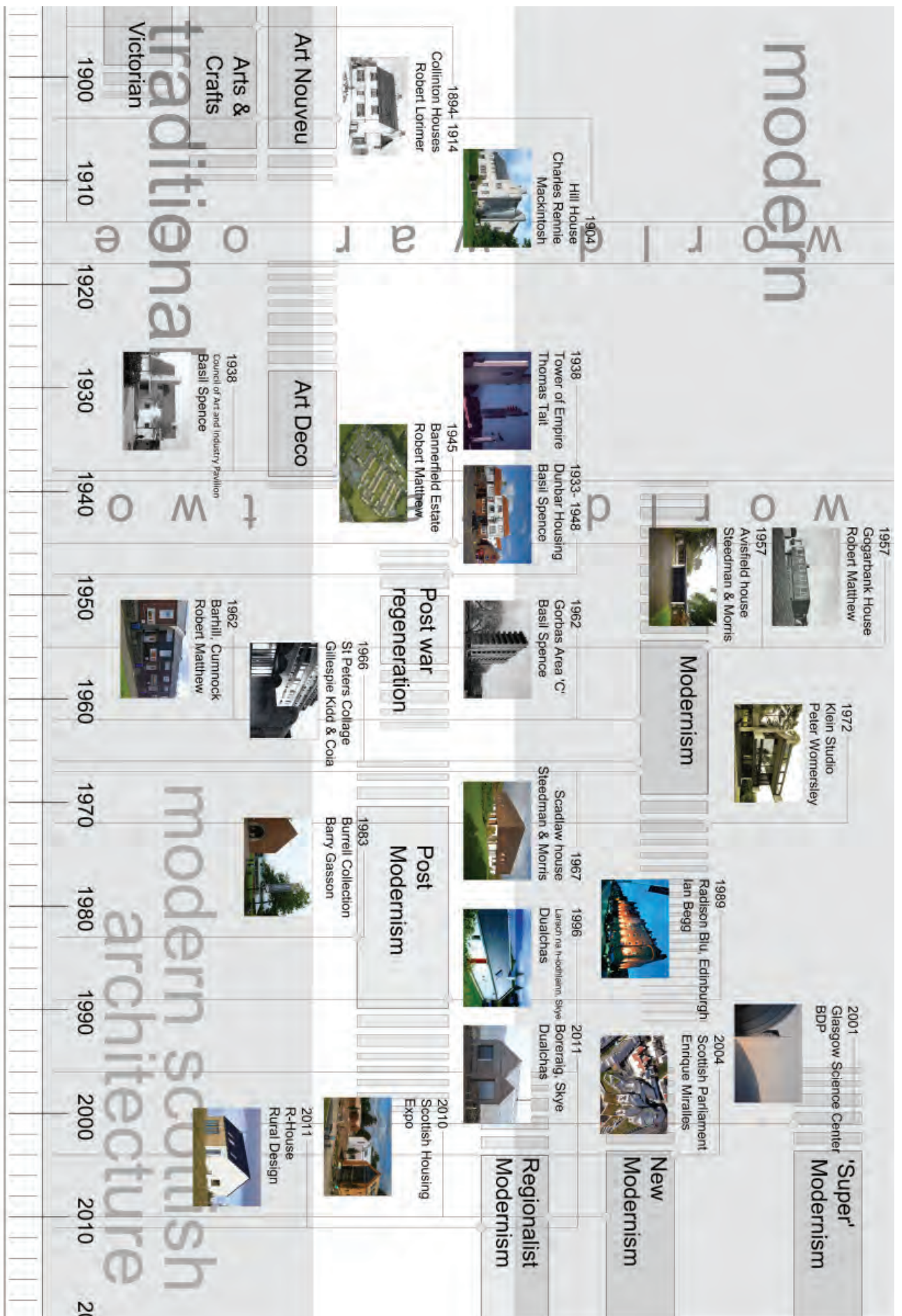


Figure 19- Overview of Scottish Architecture 1900- 2014

housing forms (Glendinning & MacKechnie 2004; Lewis 2007). Many of the award-winning examples of housing combined vernacular detailing and modern layouts (Lewis 2007). However, by 1960 urban planning and housing typologies were to change in favour of large, high-density multi-storey tower blocks in the West of Scotland due to inner city land shortages and subsidies introduced in 1965 (Glendinning & MacKechnie 2004). In other areas of Scotland such as the New Towns Cumbernauld and Glenrothes large scale low rise development was favoured. Similarly large-scale medium density urban districts on city boundaries and green belt land became common such as Whitfield in Dundee. Public sector housing began to lose favour in the 1970's falling to 78% of new builds. In parallel the economic downturn and OPEC oil embargo in 1973 led to a reduction of small-scale architectural work. During this decade criticism was growing against modernist high density housing and in Glasgow this resulted in a revival of the refurbishment of Victorian tenements and the preservation of historic housing districts (Glendinning et al. 1996). The 1980s saw the rise of private sector house building which quickly grew to dominate the market with 71% of new builds, compared to only 30% in the late 70's (Lewis 2007). Garden City planning philosophies developed by Ebenezer Howard in 1898, laid the foundations for suburban development which became the favoured typology for private sector developers (Howard 1965). During this decade there was a rapid increase in suburban developments across the country. In reaction to newly introduced planning guidelines of the time the private sector introduced traditionally informed aesthetic styles in an attempt to generate historically and contextually responsive neighbourhoods (O'Leary 1998; Maudlin 2009b). This pastiche, a superficial representation of a myriad of different historical examples and details referenced Victorian, Georgian and various vernacular rural housing traditions (Richards 1994; Maudlin 2009b). The 1990s saw a strengthening in private sector housing being responsible for 81% of the market (Lewis 2007). In contrast to the rest of the UK, off-site factory manufactured timber frame 'kit' housing became the favoured construction method of Scottish house builders in an attempt to improve construction quality. This form of construction originated in the American suburbs and is now the most common form of new housing in the highlands (Watson 1999). These standardised 'kit' designs ignored Scottish house building traditions (Lewis 2007). During this period were also many conversion projects in the urban centres that developed flats in existing buildings. The first decade of the 21st century was dominated by the private developer market, producing 84% of the country's housing (Lewis 2007). Between 2000 and 2010, the continued development of suburban schemes and suburban style schemes in rural areas. However, pressure from planning legislation saw a development of some innovative housing layouts to improve the typical suburban cul-de-sac. In 2006, the financial crisis resulted in a major decline in building across the entire sector with the biggest decline in private housing. This has continued to effect Scottish Government exemplar developments such as the Scottish Housing Expo and Polnoon.

3.1.2. Suburbanisation in Rural Scotland

“In its nature suburban housing is not urban or rural; rather, it sits somewhere in between: a no-man’s-land of poor, ill-defined thresholds and ambiguous spaces” (Sergison 2007)

The term suburbanisation can be used to describe two types of rural development.

The first is the wide spread use of suburban development layouts (medium to large scale developments) and associated suburban style housing models generally found in accessible rural settlements within commuting distance of urban centres (Richards 1994). Liff is a typical example of a small village with a major modern development following typical suburban design principles [Figure 20]. This form of development blurs the relationship between the urban and the rural, which has resulted in the widespread suburbanisation of rural areas adjacent to traditional city boundaries. Suburban style developments of detached housing often result in a mono-type and mono density layout lacking in variety of land-use and building form (Scottish Government 2005). Demography of the development can change many aspects of the identity and sustainability of a development, many of the current developments in accessible rural areas are not built for rural workers but for commuters who travel to other areas.

The second form of development uses suburban style house designs in remote rural areas, generally as smaller developments or single units on isolated building plots within the landscape (*ibid*). In remote rural areas small groups of houses provided by single client developers/landowners and small housing associations are common. One-off houses funded by private individual’s provide for themselves are also popular. The



Figure 20- Liff- Typical Accessible Rural -Suburban Development

development of single houses which are inappropriately sited can be equally destructive to remote rural areas as the large scale developments. Single houses are often built by individuals which are sometimes designed by architects but often taken from timber kit manufacturer's brochures (Richards 1994). Models such as Scotframe Rural Homes Collections are sometimes utilised without any adaptation for particular sites (Scotframe 2013b) [Figure 21]. The use of these models is discussed further in the section 3.2.2.5. Farming and crofting have been in decline for many years, with housing now having a greatest lasting effect on the character of the rural landscape (Richards 1994; Scottish Government 2005). Increased numbers of houses are required in rural towns and villages in addition to the increasing demand of second homes and holiday homes makes this a pressing issue (Scottish Government 2005; The Scottish Parliament 2009). The use of the suburban model for planning of developments in rural areas was common after the second world war and through the 1960s and 1970s. However, concerns regarding the early Scottish development in suburban areas were raised as early as 1941 by Reiach & Hurd, who highlighted the destructive growth of single houses with gardens copied ad nauseam across Scotland (Reiach & Hurd 1941). Reiach & Hurd suggested the return to more traditional forms of grouping of houses stating that it was "*based on common sense*" (Reiach & Hurd 1941, p.46). The proceeding decades saw numerous large scale developments in rural areas. The majority of recent rural housing has been provided by commercial sector developers and volume house builders, using standardised detached timber frame kit house types, organised within relatively low-density suburban style development. Mass market developments generally use UK wide '*pattern book*' suburban layouts, implemented without intrinsic relationship to the location or reference to the existing regional identity. Since the 1980's the prevalent new build housing typology in Scotland has been the detached house (Scottish Executive 2013c, p.117). This use of developer-led mass market housing models has been leading to the suburbanisation of the Scottish countryside for many years, evidenced across all regions of rural Scotland. This is a well-known issue with Scottish Government stating "*there is a skills and knowledge gap holding back the design of more qualitative, sustainable, economical, energy efficient rural housing*" (The Scottish Parliament 2009). A summary of issues of inappropriate development in Orkney Islands Council and Comhairle nan Eilean Siar revealed that there are problems in a number of Scottish rural areas.



Figure 21- Scotframe Rural Homes (Scotframe 2013b)

The same problems can be identified across Scotland's rural areas:

- *Badly sited houses, designed regardless of context*
- *High demand for plotted housing rather than clusters*
- *Ambiguous policy and advice*

- *Tinkering with details and materials rather than addressing poor design*
- *Design guide language is inaccessible*

The importance in understanding and effectively managing the relationship between the rural landscape and housing development is given greater importance when considering the current and future pressures on development. The continued development of the landscapes has a long lasting legacy on the identity of Scotland, this development has to continue and diversify utilising sustainable strategies. Consequently, future housing forms and development need to change radically if more sustainable means of living are to be achieved.

3.2. Scottish Planning and Design Legislation and Guidance for Rural Housing

This section summarised the current Scottish planning system and describes some of the resources and organisations available to assist professionals when designing residential developments. It highlights requirements and specific information available for residential projects in rural areas. The planning and building standards systems purpose is to “*have a role to play in delivering high quality buildings and infrastructure with better environmental standards... to drive up standards for planning, design and maintenance of the built and natural environment... we develop sustainable communities which are sympathetic to Scotland’s landscape and the environment ...*” (Scottish Government 2013c).

3.2.1. The Scottish Planning System

The Architecture and Place division of the government oversees the planning documentation and information, including policies, notes and details on previous projects (Scottish Government 2011c). The Scottish Planning Policy is the government’s policy on nationally important land use, planning matters and in the 2010 revision there is a greater focus on sustainable economic growth and improved place making. This policy is due to be updated at the end of 2013 (Scottish Government 2010c; Scottish Government 2012d). The National Planning Framework (NPF) identifies key strategic infrastructure to aid future spatial development at a national level and the development of Scotland’s towns, cities and countryside in the next 20 years (Scottish Government 2009a). Planning policy is represented by individual Strategic Development Plans for each of the four Scottish Regions. These regions are defined by the major cities and surrounding areas; Glasgow and the West of Scotland. Aberdeen and the North of Scotland, Dundee & Angus-central East Scotland and Edinburgh & Borders (S. A. H. Scottish Government 2013b). Each region has a separate strategic development plan (SDP). SDP’s outline where new development should take place - within, around or outwith cities covering a 20 year time scale and define the type of development be this urban, suburban or rural. A recently approved SDP is the Tayplan which encourages major fringe development of rural land surrounding the urban centres of Dundee and Perth and town centre of Cupar rather than urban development (Ewen et al. 2013). Developments of this type then come under the Local Development Plan (LDP) . The Scottish planning system is regionally implemented by local authorities under the national legislation. Local planning authorities produce their own Advice Notes. These advice notes, which contain information that the

particular authorities planning department will base approval decisions on.

Planning System Policy Levels

[Figure 22]

- **Scottish Planning Policy (SSP)**-
National Governing Planning Policy
- **National Planning Framework (NPF)**-
Strategic National Framework
- **Strategic Development Plan (SDP)**-
Strategic Plan
- **Local Development Plan LDP**- Local
Plan
- **Circulars**- Statements implementing
policy and guidance

Guides and non-legislative Information

- **PAN (Planning Advice Notes)**-
provide advice and information on
technical planning matters
- **Design Advice Guidance**- will provide
guidance and information on design
matters covering a range of practical
projects and roles.
- **Design Examples and Initiatives**-
Projects endorsed by Architecture and design Scotland and the Scottish Government.

Planning Structure

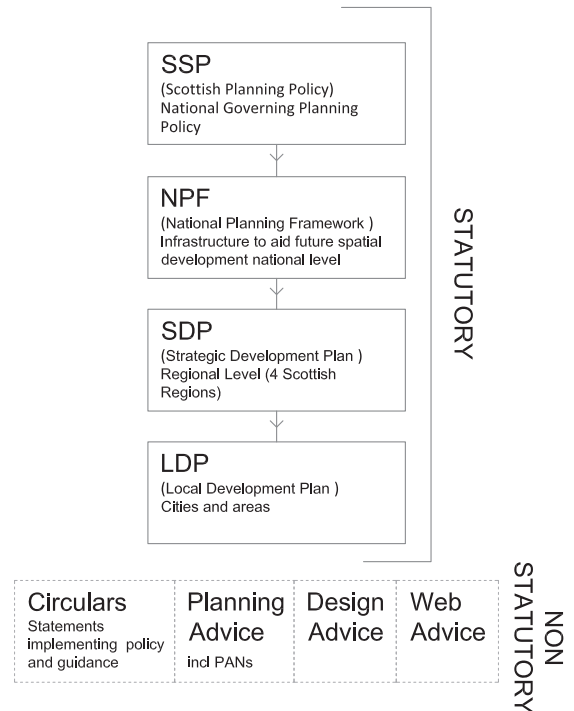


Figure 22- Planning Structure

Scottish Planning Policies

The 2010 *Scottish Planning Policy* aims to address many issues relating to identity, in particular (Scottish Government 2010c):

- Small settlements losing their identity
- The suburbanisation of the Scottish countryside
- It also aims to *“maintain and improve the viability of communities and to support rural businesses”*
- It recommends *“that development plan policies for development involving low and zero carbon generating technologies should accord with the standards, guidance, and methodologies provided in building regulations” (ibid).*

Planning and Design Guidance

In 2011 the Scottish Government created the Architecture and Place Division that focuses on place making and on sustainable economic growth and development delivery. Architecture and Place works independently of the planning system and provides a number of policy documents and design exemplars to improve placemaking and sustainability of future development of the built environment in Scotland (Scottish Government 2011b). The resources are either written documents or design projects, both proposed and built. There are two design policy documents for Scotland: Designing Places (2001) and Designing Streets (2010) these documents which have the same status in decision making as the SPP and NPF and affect every applicable planning application (Scottish Government 2001; Scottish Government 2010b; Scottish Government 2010c). Designing Streets supports Designing Places and is the first policy statement in Scotland for street design and marks a change in the emphasis of guidance on street design towards place-making and away from a system focused upon the dominance of motor vehicles (Scottish Government 2011c). *“The Designing Places policy is a material consideration in decisions in planning applications and appeals and provides the basis for the latest Planning Advice Notes (PANs)”* (Scottish Government 2011c). Designing Places, recognises the barriers to creating successful and sustainable places and calls for a shift in attitudes, expectations and practices in the design of cities, towns, villages and the countryside (Burford & Pearson 2013). It cites, in privately commissioned houses there has been a marked improvement in design quality, place specific design responses as well as improvements in the technical efficiency and sustainability of construction but these approaches have so far failed to be adequately adopted in volume house building (*ibid*).

Planning Advice Notes

The range of PAN documents is extensive and is continually revised, but they act only as advice on best practice and are not part of legislation. Current PANs offer guidance in a variety of different areas. Current PAN offer guidance and provide specific information across forty one areas with two in progress another two in development (Scottish Executive 2008d). There are specific area PANs dedicated to residential development and development in rural areas.

3.2.2. Residential Development in Rural Areas- Planning Advice Notes (PAN)

The unique identity and sensitivity of the Scottish landscape requires different design approach to urban areas. The Scottish Government, Architecture and Design Scotland (A+DS), and other organisations have developed a wealth of design guidance, legislation and suggestions for rural development since the early 1990's (Scottish Executive 2008d; Architecture and Design Scotland (A+DS) 2013).

3.2.2.1. PAN Origins

The approach and quality of rural development has been questioned for many years, originating with

various reports such as the *'Rural Housing Challenge'* (Scottish Homes 1990), *'Setting and Design of New Housing in the Countryside'* (PAN 36) (Scottish Office 1991) and *'Timber Frame Houses in the Scottish Countryside'* (Richards 1994). Points raised in these three key documents are valid, applicable and stated in today's context despite being raised around 20 years ago.

'Rural Housing Challenge' published in 1990 stated that "a new rural approach should be developed, rather than merely revamping an inappropriate urban response" (Scottish Homes 1990). The document also calls for appropriate design responses based on area by area solutions and alternative approaches to affordable housing. It defines the requirement for more affordable housing and the possibility of considering crofting examples from other European countries (*ibid*).

'Setting and Design of New Housing in the Countryside' was a precursor to the PAN 72, *Planning Advice Note Housing in the Countryside* focusing on similar points such as the introduction of out-of-character suburban housing types aiming to maintain design coherence based on regional character. The current PAN document is discussed in more detail later in this section (Scottish Office 1991).

'Timber Frame Houses in the Scottish Countryside' focuses on the use of much criticized standardised kit house designs that were prevalent over the 1980s (Richards 1994). The report calls for varied housing designs specific to areas. It states that conditions such as "*climate, landscape, character, material and architectural traditions*" all vary across Scotland's regions. It reinforces the fact that much of the timber frame design from around 1970's up to the early 1990's took misguided design cues from the legislation of the time. The publication comprehensively covers the history of Scottish traditional building and the practice of timber kit design circa 1990.

Rural Design Specific Planning Advice Notes

There are a number of current planning advice notes that aim to improve development in rural areas. These are:

- PAN 44: Fitting New Housing Development into the Landscape (1994)
- PAN 67: Housing Quality (2003)
- PAN 72: Housing in the Countryside (2005).

Much of the information in the rural PAN documentation aims to improve the design of the built environment and appears to react against poor quality previous practice from the 1980s, highlighted by Richards (Richards 1994).

3.2.2.2. PAN 44 Fitting New Housing Development into the Landscape

Although published on the Scottish Governments website in 2005 PAN 44 originates from 1994. This document was released in the same year as *Timber Frame Houses in the Scottish Countryside* as a reaction to the past decades of inappropriate residential development (Richards 1994). PAN 44 documents many of the

problems that are prevalent in current rural housing development and documents the changing effects that physical, historical, social, economic and cultural factors have on the build environment. Both publications highlight the historic relationship between urban form, climate and landscape, such as the positioning of medieval houses to minimise climatic effects. The publications between them describe the balanced relationship that the Planned Village Movement of the 18th century had with the landscape in contrast to the plotted developments of mono-type and mono density kit house layouts based around the dominance of the car.

The main focus of the report is to highlight and advise against generic development in rural areas that is damaging the identity of the rural Scottish landscape. The advice notes summarise a series of factors that have adversely effected modern residential development in rural areas (Scottish Government 2005):

Scale

- involve extensive land-take, with limited landscaping or 'green framework';
- adversely affect the visual setting of existing towns and countryside;
- evolve as a sequence of phased developments related solely to market considerations often in the absence of any overall design for the wider environment;

Density

- often result in an mono-type and mono density layout lacking in variety of land-use and building form;
- present stark contrast to the urbanity which traditionally characterises Scottish towns;
- contrast markedly with the form, style, materials and general character of the established townscape creating significant visual intrusion at the edge of towns.

Layout and Design

- are often characterised by standardised suburban designs and layouts with little diversity and lacking other uses to create focal points and landmarks. As a result they lack individuality and identity;
- have standard house types insensitive to individual locations;
- use standard palette of materials often transported over long distances and alien to the locality.

Creation of Spaces and Places

- lack evidence of success in the creation of place. There is often a lack of distinction between public and private space and an absence of landmarks and distinguishing features.

Other detrimental design issues come from the use of modern construction materials which are applied with little thought or consideration of location and positioning of new build houses. The report highlights the difficulty in applying environmental quality objectives such as protection of landscape settings, enhancement of character and identity of settlements relationship due to other conflicting development control criteria.



Figure 23- PAN 72- Housing in the Countryside (S. A. H. Scottish Government 2005b)

3.2.2.3. PAN 72 Housing in the Countryside

[Figure 23]

Housing in the Countryside is an update of the 1991 PAN 36 document and was introduced in 2005 (S. A. H. Scottish Government 2005b). It defines the siting and design of rural housing and is meant to be read in conjunction with PAN 44. The updated advice note relates to the increase number of people wanting to live in the accessible parts of the countryside whilst commuting to local towns and cities within commuting distance. The number of people who wish to live and work in the countryside has also increased though technological changes facilitating home working practices. The holiday home market also has an effect on the existing housing market along with the requirement for new build accommodation. The document addresses rural housing design as 'areas' and 'factors', within which information on best practice is provided which includes factors such as:(S. A. H. Scottish Government 2005b):

Location

- *Landscape*
- *Layout*
- *Access*

Housing Design

- *Scale*
- *Materials*
- *Details*

The report accepts that development of rural areas is required but stresses that careful design is essential. It suggests a balance between traditional features and modern contextual design; *“Traditional buildings can be an inspiration but new or imaginative re-interpretation of traditional features should not be excluded”* and *“the aim should be to develop high quality modern designs which maintain a sense of place and support local identity”* (S. A. H. Scottish Government 2005b, p.7). This balance can be noted in many examples from the *Inspirational Designs* web page (S. A. H. Scottish Government 2012d). The document again states that groupings of new houses *“should not be suburban”* and suggests that any development should be: *“small in size, and sympathetic in terms of orientation, topography, scale, proportion and materials to other buildings in the locality”*. The document stresses that the building should consider the impact it has on the landscape and states that designs must reflect the surrounding landscape. A well-designed house must be informed and respond to its context, reflecting its surrounding landscape, rather than *“a house which is designed without regard to the context and placed within a site”* (S. A. H. Scottish Government 2005b, p.11). It recognises that a well-designed building placed within an unsuitable site can still fail. Furthermore it states that *“every settlement should have its own distinctive identity. This is determined in part by the local characteristics of the area’s architectural style of individual buildings and the relationship of these buildings to each other”* (S. A. H. Scottish Government 2005b, p.24). With regard to building form it advises to *“...adapt the best from the local elements and to interpret traditional shapes and sizes into a modern context...this will allow the building to contrast and compliment the surrounding settlement”* (S. A. H. Scottish Government 2005b). The document encourages the use of local materials, stating *“The greater the use of local materials, the more the house may reflect aspects of the local character. This will also help to contribute to sustainability”* (S. A. H. Scottish Government 2005b). Overall the PAN 72 gives good design advice, whilst highlighting issues that lead to poor quality development. The document does not however comment on energy efficient siting of housing in any detail or give reference to relevant documentation.



Figure 24- PAN 67- Housing Quality (Scottish Executive 2003)

3.2.2.4. PAN 67 Housing Quality

[Figure 24]

PAN 67, Housing Quality is intended to illustrate how Designing Places should be applied to new housing (Scottish Executive 2003). The guidance is appropriate to all housing, but places particular emphasis on the failings of suburban housing citing character, identity and variety as main issues. Additionally, it criticizes the use of inappropriate materials and lack of relationship to their context. The onus on the design for the car in suburban development and effect on the streetscape is mentioned. The importance of cars in suburban developments and detrimental effect on the streetscape are issues that were later addressed in more detail with the introduction of the *Designing Streets* in 2010 (Scottish Government 2010b). The document picks up other relevant points similar to the previously mentioned PAN's such as suggesting a considered relationship with the existing context, reflecting local forms and materials. The document also considers energy efficiency criteria, encouraging the use of energy efficient forms of housing such as terraces or flats, basic sheltering through the built form, services to the north & habitable rooms to the south and consideration of the micro climate of the chosen site to improve public spaces. This simple but important checklist appears to be continually overlooked in many residential developments. In addition to the main design points made in the document the notes mention that *"in general, the less urban a place is, the less likely it is that the local authority planning department will have design skills"* (Scottish Executive 2003, p.27).

3.2.2.5. Alternative Interpretations of PAN Documentation

Scotframe a timber frame manufacturer and Dualchas a small architectural practice both use alternative interpretations of the PAN 72 documents (S. A. H. Scottish Government 2005b)[Figure 25].

Both firms use Scottish policy to create alternative identities and approaches to suburban models which highlights the divergence in approaches and differences in the resulting quality of the products. Scotframe produces housing models for the self-build market and mass market developers. The particular range of housing models attempt to reproduce traditional forms and detailing using a reproduction of an simplistic aesthetic. It could be interpreted as a *“simple-minded attempts to revive the hypothetical forms of lost vernacular”* (Frampton 1983, p.21). Scotframe’s Rural Home collection brochure uses

restructured quotes from PAN 72 as an introduction to their collection using descriptions like: *“high quality design, responsive to their setting...”* (Scotframe 2013b). Ironically they are producing models that have been standardised across the countryside. This statement aims to illustrate their standard Rural Homes collection which can be placed on almost any rural site with the necessary planning permission and raises the questions:

- What scale are different designs appropriate, national, regional or settlements?
- What qualifies as good design in rural areas?
- What is an appropriate contextual response?

Dualchas concentrate the majority of their work in Western Scotland and the surrounding islands, designing at a regional, rather than national level. Dualchas also quote from PAN 72 as part of planning documentation, using the guidelines as prompts to inform their design standpoints, in particular they cite: *“[the] purpose is to create more opportunities for good quality rural housing which respects Scottish landscapes and building traditions”*. Dualchas place themselves as having *“helped develop a modern vernacular for the Scottish countryside based on traditional architecture...Houses respect the past they do not resort to pastiche”* (S. A. H. Scottish Government 2005b; Arnold-Forster & Dualchas 2008). They reinterpret the existing identity of traditional Scottish housing, modernising planning and aesthetics. Much of their work could be termed as Critical Regionalist. Frampton’s statement could describe Dualchas work: *“[to] mediate the impact of*



Figure 25- Scotframe Brochure

universal civilization with elements derived indirectly from the peculiarities of a particular place" (Frampton 1983, p.21). The inherent quality and relationship to place that designers such as Dualchas offer with their bespoke designed developments is an important factor which should be considered in the future of commercial housing. These particular different readings and interpretations of the PAN document illustrates how alternative design strategies can reference the same documentation but result in wildly differing qualities.

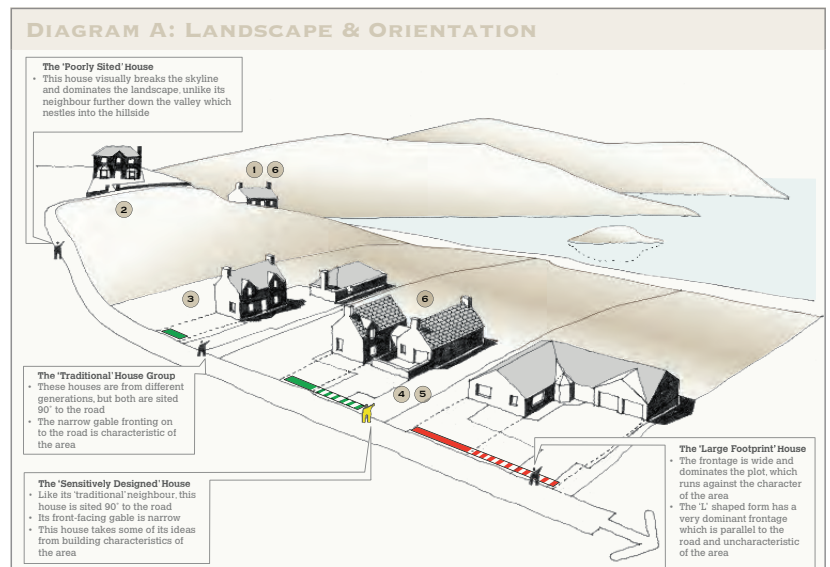


Figure 26- Outer Hebrides Design Guide (Comhairlie nan Eilean Siar 2010)

Different readings of guidance will be submitted in planning applications for many rural developments. With current planning structure it is the planning authority that ultimately makes the decision on the use of the planning documentation and design quality of the proposal.

3.2.3. Rural design: Future Landscapes

The Scottish Government have commissioned their own rural house designs in collaboration with developed rural designs and presentations in collaboration with key suppliers and architects. Orkney Islands Council and Comhairlie nan Eilean Siar led an initiative to develop new design guides, an Island House Type based on a timber kit and masterplan morphology. The initiative had a series of outcomes; new design guides, an Outer Hebrides Kit house re-design and masterplan training (St Andrew's House Scottish Government 2011h). The Outer Hebrides Kit house re-design outcome is discussed further in Chapter 7. The summary document criticises the continued prevalence of suburban housing forms on the islands that *"do not respond, sensitively, to landscape considerations"* and highlights the problems associated with the suburbanisation of the rural Scottish countryside (St. Andrew's House Scottish Government 2011b, p.6). It also highlights the suburbanisation of many areas of Scotland. It emphasises issues with design quality *"examples of well-designed houses in the countryside have become the exception, not the rule"* and calls for local design (*ibid*). It calls for local design principles and guidance from local authorities to highlight the regional differences through design guides. As part of the initiative a diagrammatic, simple design guide was produced for the Outer Hebrides [Figure 26] (Comhairlie nan Eilean Siar 2010). The masterplan training with Dualchas Building Design reinforced the designing streets methodology, used for Polnoon, but in the Orkney context (Scottish Government 2009b). The views stated and the approaches taken in this initiative appear to be again encouraging high quality, contextual design that responds at a regional level. There are only sweeping

statements concerning energy efficient design. The kit house re-design study is similar to many houses appearing to take little interest in energy efficient design rather than considering a holistic approach at a design stage.

3.2.4. Single Houses in Rural Areas- North Ayrshire Guidance

[Figure 27]

There are a number of similar government and council developed

initiatives that aim to improve design quality, particularly in rural areas. Design Guidance: *Single Houses in Rural Areas* is a collaboration between North Ayrshire Council & Glasgow architects Anderson Bell Christie. The document takes a different approach to the *Rural design: Future Landscapes* as it is guidance aimed at the client as well as building professionals. The main content is a precedent study of a range of architectural approaches to modern rural development and exemplary house designs. The guidance also clearly defines the design drivers for single houses in rural areas. The drivers are not suggestions but they are enforced in the Local Development Plan (Anderson Bell Christie & North Ayrshire Council 2013):

- “Outstanding quality of design”
- “Distinctive and responsive to its setting”
- “Complements and enhances the established character of the area”
- Located away from other buildings therefore “considered as part of an established rural landscape”
- Conversion or rehabilitation of existing building is not possible
- “Not of a suburban character”
- Positively endorsed by the council or A+DS

This method for actively enforcing key drivers in policy and illustrating examples of good design should act as an effective way of enforcing high quality design in rural areas.

3.2.5. Architecture and Design Scotland (A&DS)

Architecture and Design Scotland was established by the Scottish Government in 2005 and is badged as Scotland’s champion for Excellence in placemaking, architecture and planning (Scottish Government 2011a). It claims to have “wide and proactive role in advocating the benefits of good design and place-making”



Tigh na Dobhran, Studio Kap © Keith Hunter



Port nan Each, Cameron Webster Architects

A small house that addresses the scale of its site and creates impact in a large landscape. It literally reaches out to the Loch and exploits the views beyond over the water in all directions.

The materials are hard and man-made - render and metal - in stark and deliberate contrast to the natural rock and shore 'a place where the natural and the manmade meet'.

On land it settles back into the wooded hillside and makes the most of the extended site which has a tree-lined burn.

The plan of this house outlines best its concept...



Although a conversion of an existing house (the original roof is just seen in this view) previously a naval outlook post, this house owes its character to its new architecture.

It is right at the water's edge and exploits the views across down the Firth of Clyde. To make the most of this the elevation facing the water has full height frameless glazing.

This houses demonstrates the importance of the quality of materials and detailing. The massing of the overall completed piece is also sensitive and characterfully domestic.

Figure 27- North Ayrshire Guidance (Anderson Bell Christie & North Ayrshire Council 2013):

(Architecture and Design Scotland (A+DS) 2009). A+DS have a history of producing high quality documentation aiming to raise design quality across Scotland. They are also responsible for partnering in many exhibitions showcasing good design. A+DS plan an active part in the design community in Scotland, producing high quality documentation and hosting exhibitions that will help to raise the profile of Scottish design. In 2006, A+DS developed an exhibition and book highlighting rural housing issues: *30% New*

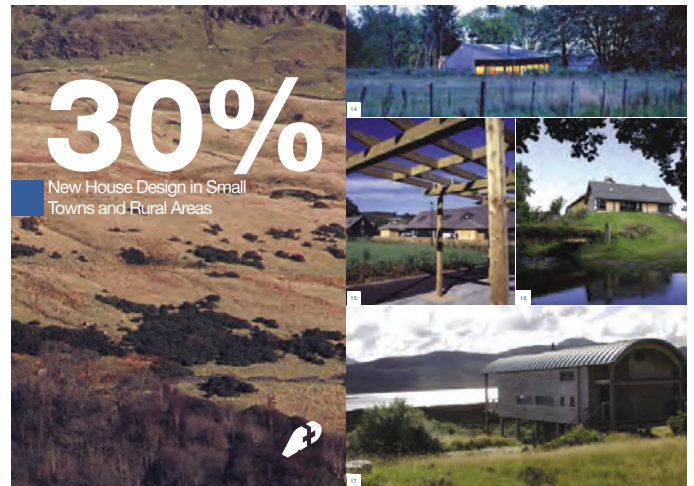


Figure 28- 30% (Architecture and Design Scotland (A+DS))

House Design in Small Towns and Rural Areas. [Figure 28] It illustrated examples of high quality design and advised that *"inappropriately designed and sited dwellings can damage the larger sweep of the landscape: different solutions are called for in rugged, open vistas, from smaller irregular valleys, in woodland or adjacent to other buildings"* (Architecture and Design Scotland (A+DS) 2006, p.14). It advocated site-specific responses in design to local landscapes and through the sensitive positioning of new development. This view is held by many contemporary architects and is also reflected in the Governments Planning Advice Notes (PAN 72), *'Housing in the Countryside'* (S. A. H. Scottish Government 2005b, p.11). They also suggest that inspiration can come from older forms of building, current climate change issues, use of local materials and innovative technology. These are suggestions mirrored in PAN documentation. In addition there are some environmental recommendations; that houses should exploit passive solar gain, make use of views, address and question *"how best to balance the demands of sensible use, durability and appearance"* (Architecture and Design Scotland (A+DS) 2006).

3.2.6. Saltire Society- Housing

Although the Saltire Housing is not part of the Scottish Government or associated with legislation it has had a significant effect on the design of Scottish Housing. The Saltire Society was originally founded in 1936 by academics in Glasgow University with the aim of *"arousing critical appreciation of the arts in Scotland"* (Glendinning et al. 1996; Lewis 2007). It was established to both protect Scottish culture and to progress Scottish culture (McKean 1986). The publication of *Building Scotland- Past and Future* established the societies architectural standpoint at this time (Reiach & Hurd 1941). The important publication proposed a compromise between modernism and traditionalism (Lewis 2007). In the Saltire Society 1937 it introduced an award for good housing *"in conformity with the Scottish architectural tradition"* (McKean 1986). The housing award was suspended over World War II and re-established in 1948. The current awards contain categories such as Small Scale Housing Development, Innovation in Housing and New Build Private Dwelling (Saltire Society 2014b). The awards allow for the identification of examples of high quality housing across Scotland. Many of the design exemplars discussed and analysed in the remainder of the thesis have been

shortlisted or are winners of a Saltire award. They state that the *“Awards form an important reminder of the vital part that housing plays within our lives and culture”* (Saltire Society 2014b). The awards also document contemporary, high quality architectural design of the time which creates a valuable resource documenting Scottish residential architecture. Lewis in the Saltire societies 70th anniversary publication summarises that *“there may be no fixed or appropriate architectural language or building form that is uniquely appropriate for housing in Scotland. But what is important is that new housing meets the needs of contemporary occupancy contributes the broader quality of the built environment”* (Lewis 2007, p.3).

3.3.Traditional References in Contemporary Architecture

Throughout architectural history there are many references to traditional building styles and forms. Some references to traditional and vernacular enhance the connection to the historic context, however some are potentially damaging to the design quality and surrounding context. The built environment and architecture can create many forms of identity intrinsically linked to the cultural grain; public buildings, developments, streets, towns; cities. The way in which a developer, planner or architect responds to the surround identity can have a profound effect on the success of the design outcome. Therefore the way that identity of a place is observed, considered and interpreted will fundamentally effect the outcome of a design project. The relationship to existing and creation of new identities can be used to categorise architectural design approaches. Derakhshani proposes that there are four main strategies for defining identity (Derakhshani 2009):

- Reproduction of identity- which utilises existing identity and existing context.
- Recreation of identity- which develops from an existing identity.
- Appropriation of identity- which takes an existing identity and implements it in a new context.
- Invention- which creates a new identity within a context.

3.3.1. Developer References to the Past

Within architectural movements it is commonplace for Scottish architects to take reference from different elements or revive styles from the traditional Scottish architectural heritage. This can take the form of housing details, materials, planning and forms. This recurring revival of past styles is theorised by Charles McKean as a cyclical progression. McKean highlights the revival cycles in Scottish architecture since the 18th century which are still occurring almost 30 years after the initial idea was proposed (McKean 1986; Glendinning et al. 1996, p.482). Scottish developer housing from around the 1980s use reproductions of familiar housing styles. These reproductions



Figure 29- Rural Timber Kit House (Maudlin 2009b, P9)

are encouraged in part by contemporary legislation and part by buyer demand. Legislation developed in the 80s and 90s intended to improve the design quality and relationship to context by referencing traditional building types, discussed in section 3.2.2.1. (Scottish Office 1991). This legislation is a reaction against what was “perceived as the ‘characterless’ modern architecture of the 1970’s” (O’Leary 1998; Maudlin 2009b). Maudlin suggests that



Figure 30- Google Street View 2013, Poundbury

this is in order to safeguard a memory of a specific time, this form of neo-traditional styling generally reflects residential types found predominantly in mid-18th century (Maudlin 2009b, p.53) These models are typically a combination of different traditional housing styles to create the identity of an archetypal housing form. [Figure 29]. These models often use forms, materials and detailing sometimes adapted from English house builders pattern books often not traditionally found in Scottish rural areas (Richards 1994). Therefore these kits are not normally adapted to take account of Scottish tradition or regional variation resulting in standardisation of appearance throughout the country (Scottish Office 1994). The typical thin timber frame construction methods utilised in many developments is very different to the detailing of traditional stone built houses with thick walls and deep set windows (Richards 1994). Therefore these designs and layouts are rarely appropriate to their context and are imported from different geographical or urban contexts. The reference or copying of traditional types is taken to its extreme in the Poundbury development in Dorset (Fladmark et al. 1991). [Figure 30] Poundbury is a modern recreation of a Georgian English village master planned by Leon Krier in the late 1980s built according



Figure 31- Rural Timber Kit Example (Scotframe 2011)

to the design principles of Prince Charles who sought to challenge the post-war suburban development trend in town planning (Charles 1989; Krier 1998; Hardy 2006). However, the copies of Georgian buildings are interpretations of house types that have little relationship to modern cultural and technical context and could be termed as pastiche (Dixon 2013). The replication of past design styles is summarised by an analogy used by Richards, “*It is always the best policy to speak the truth, unless, of course, you are an exceptionally good liar*” (Richards 1994; Jerome & Barr 1892).

Developers and kit frame manufacturers have taken notice of criticism and legislation by developing rural

specific house designs which attempt to revive Scottish traditional building forms (Scotframe 2011; Lawlor, Architecture+ Design Scotland & Scottish Government 2009). These house types comply to the generic planning guidance for buildings suitable for construction in the countryside due to their historic reference (Scotframe 2011)[Figure 31] . They attempt to replicate typical forms, some use similar detailing and many alter external materials in order fit into rural settings. However, attempts to replicate previous design styles with contemporary materials and scales responding to today's consumers requirements leads to a confusing design outcomes attempting to produce a traditional visual aesthetic with modern materials and construction techniques and proportions. These designs could be termed as pastiche due to their unconvincing imitation of traditional styles with little or no specific relationship to their cultural context. A number of architects have developed timber kit sister companies who develop more suitable designs such as; Rural Design, Dualchas and Neil Sutherland. These timber kits aim to improve upon the Scotframe's Rural Designs model however these designs have not received much uptake within the mass market housing sector.

3.3.2. Critical Regionalist Theory in Scottish Architecture

There are many examples of contemporary Scottish architecture practices in the Scottish Highlands and Islands whose work also reference traditional buildings such as those designed by Dualchas and Rural Design. The appropriate referencing of a traditional styles is prevalent in rural areas. There is a lack of evidence of architectural theory through literature and scholarly writings from many firms who design some of the leading qualitative work in Scotland other than 'ethos' sections on web sites or through planning and design statements. It would appear that theoretical standpoints taken by Scottish architects appear to be generated by past architectural projects, other inspiration from various sources and experience of the legislation which governs the built work rather than a written theoretical framework that governs the key ideas through to the design

of the work. However there are many examples of the contemporary Scottish architecture in rural areas which could be termed as Critical Regionalist architecture that have a strong relationship between building and region including that of Rural Design and Dualchas (Lewis 2010; Architecture and Design Scotland (A+DS) & Guest 2011) [Figure 32,Figure 33]. The concept of 'Critical Regionalism' was developed in response to the lack of regional



Figure 32- Dualchas, The Shed, Skye. Image Andrew Lee (Architecture and Design Scotland (A+DS) & Guest 2011)

references of modernism in the 1980s by Tzonis and Lefaivre then adapted and popularised by Kenneth Frampton (Tzonis & Lefaivre 1981; Frampton 1983). In 1983 Frampton argued that modernization and instrumentalism had become overbearing and that a critical approach to the regional could provide a theory for developing contemporary architecture (Lewis 2010). Some examples of 'regionalist' architecture have a tendency to resort to inappropriate references of the vernacular, however Critical Regionalism seeks to use



Figure 33- Rural Design, The Black Shed, Skinidin, Skye (Architecture and Design Scotland (A+DS) & Guest 2011)

critical and appropriate references to the vernacular, cultural context and local context. Critical Regionalism defined by Kenneth Frampton relies on a series of points to critically respond to the context (Frampton 1983):

- 1) Critical of modernisation
- 2) Concisely bounded architecture
- 3) Architecture and a tectonic fact
- 4) Stress site factors
 - Topography
 - Local Light
 - Climate
- 5) Tactile Elements
- 6) Reinterpreted Vernacular Elements
- 7) Escape universal civilisation

Guest positions Critical Regionalism as providing "*the basis for a refreshing alternative to modernism's lack of interest in the particularities of locality or place and its preference for universal social solutions*" (Architecture and Design Scotland (A+DS) & Guest 2011). Many examples of well-respected Scottish architecture have a strong connection with critical regionalist approaches and designs. The



Figure 34- Dualchas Two Byres (Dualchas 2011)

application of critical regionalist approaches can be identified throughout Scottish architectural history. In 1941 the *Building Scotland* publication called for a return to the Calvinist tradition of simple buildings that use local materials (Reiach & Hurd 1941; Lewis 2010); Scottish modernists work such as the designs of Robert Matthew, Morris and Steedman, Peter Womersley and Gillespie Kidd and Coia display strong relationships to the traditional and surrounding context to create architecture that is specifically Scottish (Lewis 2010). Many contemporary Scottish architects also have strong responses to the site context. In the later half of the 1990's there was a wealth of intervention projects from Richard Murphy, Malcolm Fraser and Page & Park (Architects Journal 1999; Scottish Arts Council 2002; The Lighthouse 2014). In the last decade there has been an evident reintroduction of regionalist thinking in Scotland. The '*Architecture in Scotland 2006-2008: Building Biographies*' exhibition in the Lighthouse, Glasgow discussed, theorised and compared Scottish examples of regional architecture along with examples from Europe (Lighthouse 2008). Key examples of contemporary rural critical regionalist architecture are Rural Design and Dualchas who Guest uses as case studies in the article "*National Architecture*" (Architecture and Design Scotland (A+DS) & Guest 2011). Both Dualchas and Rural Design's references to the past are not generally thought of as pastiche, but modern reinterpretations. Their common approach is to develop the existing traditional identity with modern technology and design aspirations. High quality, contemporary interpretations of the traditional Scottish built form commonly utilise similar detailing styles, geometric forms and external materials. The designs are generally site-specific taking cues from the surrounding context, this allows these developments to help enhance the identity of rural Scotland. Current planning advice notes specifically encourage this type of development in rural areas "*where possible, the aim should be to develop high quality modern designs which maintain a sense of place and support local identity*" (S. A. H. Scottish Government 2005b, p.7). The same advice notes "*advocate the use of modern scaled horizontal openings for beneficial solar gain*". This feature is seen extensively across both Rural design and Dualchas designs. [Figure 34] Many of the rural exemplars of the Scottish contemporary architecture found on the Scottish Government website and Saltire Housing Awards feature regional and traditional materials forms and details. These examples appear to coincide with the suggestion that the combination of critical regionalist architecture and sustainability can be effective in rural Scotland due to its scale (Architecture and Design Scotland (A+DS) & Guest 2011). At a smaller scale the cultural identity of a place and its people are easier to respond to. Additionally the identity of place and orientation, climate and resources can be better addressed. Regionalism and Critical Regionalism are topics which have become contemporary issues that are now closely linked with sustainability and identity. The examples used for the study in chapter 7 are a mixture of qualitative architectural examples that could be termed as Critical Regionalist and other examples more of a literal formal approach to traditional building forms.

3.3.3. Contemporary Scottish Alternatives to Suburban Layouts

Although a significant amount of the housing produced in Scotland since the 1980s has been utilised mass-market suburban models with little connection to their context, there are examples of high quality housing, many one off houses but also larger scale developments. There have been a number of contemporary

projects that respond to the rural suburbanisation and the need for higher design quality in Scottish housing. Two such projects are; the Scottish Government endorsed Polnoon masterplan and the Scottish Housing Expo. The Polnoon development attempts to make use of the regional approach described in the previous section, the Scottish Housing Expo takes a different approach.



Figure 35- Polnoon Picture Book (St Andrew's House Scottish Government 2009d)

Polnoon

[Figure 35]

The Polnoon project redesigns a developer masterplan on the outskirts of Eaglesham, using the *Scottish Government's PAN 76* and *Designing Streets* documents in practice, with the ambition of building a "Conservation Area of Tomorrow" (St Andrew's House Scottish Government 2009d). The Polnoon project originated as a developer layout plan for 92 houses. The Scottish Government formed a new design team to reassess the original development. A detailed study on the existing town and surrounding buildings was performed to create a "contemporary yet contextual architectural vocabulary" (*ibid*). The design team consisted of the contractors Mactaggart and Mickel, architects Proctor and Matthews and Waterman Boreham transport engineers (Scottish Executive 2013e). The new proposal contains 121 houses divided up into 4 quadrants in order to relate to site-specific features around the site. The masterplan creates a hierarchy of shared surface – streets, lanes, courts and a central square. Most of the standard developer house types have been retained but 'dressed' in new elevations. Architectural features and details have been adapted from the surrounding historical vernacular buildings to "visually respect the evolution of Eaglesham" (*ibid*). One new L-shaped housing type was added to the new masterplan to create corners and courtyards.



Figure 36- Scottish Housing Expo (Scotland's Housing Expo 2010a, P7)

Scottish Housing Expo

[Figure 36]

The Scottish Housing Expo utilises the Expo model popular in Finland since 1970 (St Andrew's House Scottish Government 2011i). The Expo sought to showcase Scottish architects and stimulate quality design and raise the expectations of the public in house design in Scotland (Scottish Government 2008b). The Scottish Housing Expo opened in 2010 and is located at Milton of Leys, a rural site five miles from Inverness. The generator for the house designs was a design competition

launched in January of 2007 under the name of The Highland Housing Fair (Scottish Government 2008b; St Andrew's House Scottish Government 2011i). The masterplan was designed to present an alternative to developer style housing layouts.

The 52 houses are comprised of mainly detached, semi-detached and terraced housing typologies. The 27 different house types are all unique, and show a diverse range of approaches to housing design which are meant to create a *"modern vernacular of sustainable architecture"* (Scotland's Housing Expo 2010b). The intention was that the Scottish housing Expo would introduce designs that would showcase the work of leading architects in the residential sector and offer an alternative lifestyle which is *"more eco-friendly and sustainable, in a home built for energy efficiency that respects natural resources and uses them creatively"* (Scotland's

Housing Expo 2010a). The original development concept was that the houses would be financed by the architects who participated in the competition. However, the financial crisis required alternative funding approach which delayed the construction and opening of the development. Following the completion of *The Scottish Housing Expo*, it received a lot of criticism for the rushed construction and the delay in its completion (McKenzie 2010). Many architects involved in the competition took a backseat to construction process, many of the buildings were completed using a design and build contract. This led to the contracting taking more responsibility and the reduction in finish quality through the majority of the houses. The authors personal work on the Plot 9 house demonstrated first-hand the effect of the financial crisis on the outcome of many of the Scottish Housing Expo examples. The folding of contractors and ever tightening budgets affected the finished designs, it could be argued that the Expo did not portray modern Scottish Architecture as well as intended (Woodman 2011).

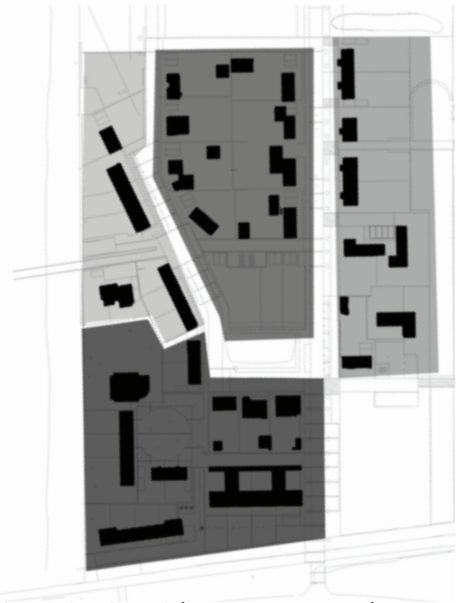


Figure 37- Scottish Housing Expo Plan (Scotland's Housing Expo 2010a)

Polnoon and Scottish Housing Expo Conclusion

However the Scottish Government Planning Exemplar Polnoon succeeds in illustrating the correct use of *Designing Streets* and *PAN 76* and the positive effect this can have on masterplan design standards. However, the *'re-dressing'* of standard housing models led to a confusing mixture of features, materials and proportions. The masterplan is an improvement on the typical suburban plotted layout. But, it appears not to reference the existing planning layout which is a mix of suburban development and lotted lands. The Scottish Housing Expo succeeds in bringing many unique designs together, allowing the public to see what is

possible regarding contemporary Scottish design. However, despite initial efforts to create “*near-continuous frontage lines [to] create enclosed streets*” the Expo masterplan still resembles a plot by plot layout used by suburban housing due to the limited use of isolated housing typologies and the masterplan design (Scottish Government 2008b; Brown 2010). [Figure 37] It is clear from the outset that each of the houses have been designed in isolation, have their own agenda and make their own personal statement on behalf of their associated architect which may have impacted on sales (Brown 2010). The two projects discussed altered various aspects of housing development; the Expo concentrating on house design, Polnoon concentrating on context and masterplan layout. In some ways these developments still share much in common with suburban housing developments. The change of either masterplan or housing leads to alternative solutions, but not radical ones.

3.4.Scottish Rural Housing and Planning Summary

“there are still too many examples of houses which do not respond, sensitively, to landscape considerations. The result has been the suburbanisation of many Scottish rural areas. Consequently, examples of well-designed houses in the countryside have become the exception, not the rule.”- From the Rural Design- Future landscapes initiative (St. Andrew’s House Scottish Government 2011b, p.6).

Scotland has seen suburbanisation of many rural areas since the 1960s and 1970s. This problem is particularly prevalent in accessible rural areas, close to larger settlements, due to the increased requirement for housing (Sustainable Development Commission & Dwelly 2009). In the 1980s the introduction of planning guidance as a reaction against what was ‘*characterless*’ architecture of the 1970’s resulted in neo-traditional standardised ‘kit’ designs which generally ignored Scottish house building traditions (O’Leary 1998; Maudlin 2009b; Lewis 2010). The housing designs are often badly sited if used individually or used as part of larger scale suburban development. The suburban model is described as mono-type and mono density layout lacking in variety of land-use and building form (Scottish Government 2005). The over use of the mono-cultural suburban development pattern is causing parts of some villages to resemble suburbs divorced from the city rather than separate self-sufficient settlements. The aim to improve design in rural areas has been repeated in legislation, PANs and Government presentations for more than a decade. The problem of suburbanisation was first raised in planning documentation published in 1990. The ‘*Rural Housing Challenge*’ document that discouraged “*revamping an inappropriate urban response[s]*” in rural areas (Scottish Homes 1990). The 1994 PAN 44 again highlighted issues with; plotted development, modern building materials, car dominated plan, etc. (Scottish Government 2005). These design issues specifically define the characteristics of suburban development. The Government’s current PAN guidance rejects suburban groupings of houses, calling for developments that are sympathetic to the local context (S. A. H. Scottish Government 2005b). The 2010 *Scottish Planning Policy* calls for new development to respond to the specific local character of the context, fit in the landscape and seek to achieve high design and environmental standards (Scottish Government 2010c). Although alternative approaches have been developed such as the one set out in *Designing Streets*, these have seen little application in practice. Additionally some stakeholders

take alternative interpretations of the documentation which can lead to poor or inappropriate design quality solutions.

In contemporary Scottish architecture there is a renewed interest in Critical Regionalist theory. This is evident through the works of small rural architecture practices such as Dualchas and Rural Design, who describe themselves as having a respect for the past offering well-crafted designs that complement the rural environment (Dualchas 2013a; Rural Design 2014). The majority of their designs are for privately commissioned houses. Therefore there has been a marked improvement in design quality and sustainability of the development of privately commissioned houses, but again has seen little adoption by the mass market housing developers.

The planning system and implementation of the policy documents need to improve to fully assesses the quality of architectural design particularly in rural areas. PAN 67 states that as a general rule, planning authorities on smaller rural areas are less likely to have design skills, or have the ability to negotiate on design issues (Scottish Executive 2003). Therefore, the lack of expertise in smaller areas could be contributing to inappropriately designed residential development in rural areas. The scale of residential development required in the future could continue to have a detrimental effect on the landscape of rural Scotland if developed using the typical models found in the last few decades. In order to create sustainable places and communities in Scotland which allow rural identity and culture to progress sustainably, alternative approaches using appropriate architectural forms are required and these intrinsically need to take into account appropriate passive solar optimisation strategies to achieve more sustainable rural housing solutions.

DEVELOPMENT OF ULTRA-LOW ENERGY HOUSING- STRATEGIES, REGULATIONS AND SOLUTIONS

Chapter 4



4. DEVELOPMENT OF ULTRA-LOW ENERGY HOUSING- STRATEGIES, REGULATIONS AND SOLUTIONS

This section charts the impact that worldwide and European climate change, energy reduction and carbon saving has on the UK's related legislation and an overview on current residential legislation.

4.1. International and European Context, GHG, Renewables and Energy Use

[Figure 38]

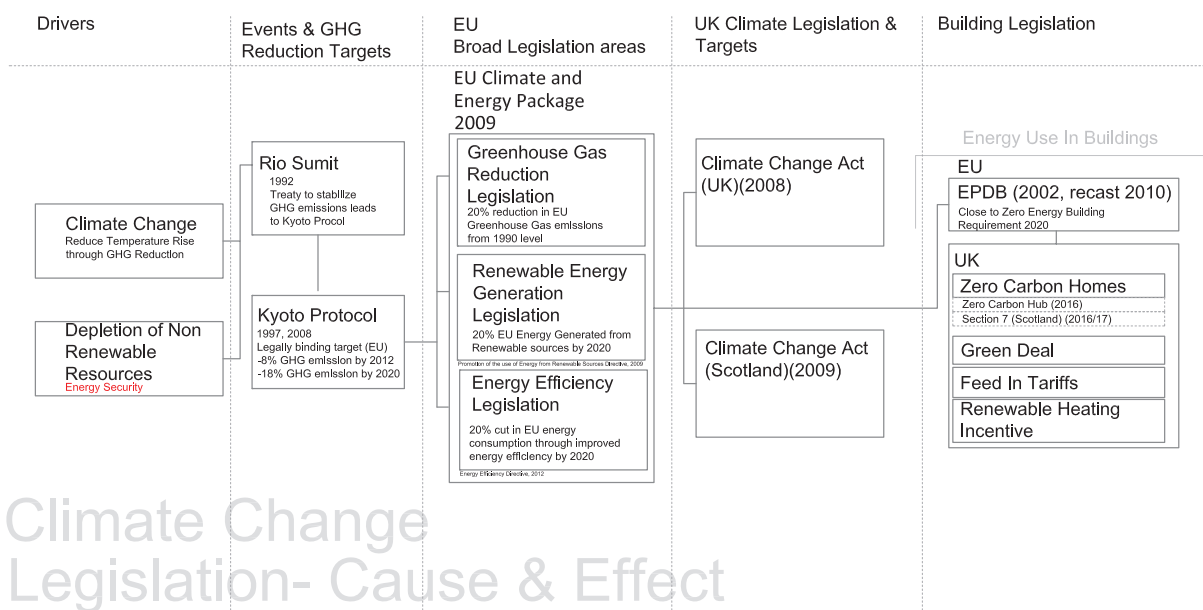


Figure 38- Drivers and Regulatory Requirements for Zero Carbon Housing

The drivers and regulatory requirements for the development of Zero Carbon Housing. The diagram illustrates the broad drivers for the legislation on the left with the housing legislation to the right.

During the last century the decreasing availability of oil and fossil fuels encouraged research into more efficient housing technologies. Since the 1992 Rio Earth summit low energy housing research has responded to legislation aiming to reduce greenhouse gas (GHG) emission which has been linked to climate change. The European commission has enforced a series of legally binding targets for GHG emission reductions through renewable energy generation and increased domestic energy efficiency. The holistic target is to reduce GHG emissions (including carbon dioxide) by 80%-95% by 2050 in order to limit global warming to 2° degrees over the pre-industrial average (United Nations 2008; UNFCCC 2012b; European Commission 2013; European Parliament 2010). The EU renewable energy generation legislation targets aim to change the current reliance on non-renewable fossil fuels with uncertain futures such as oil and gas to 20% renewable energy generation technology by 2020. This target aims to provide future energy security and affordability within the EU by importing less energy and fossil fuels. In order for member states to adhere to these legislations, they have generated their own guidance, approaches and legally binding legislation in each of these areas. Generated from these wider aims the EU has called for all new houses to be Nearly Zero Energy buildings (NZEB) by 2020,

this aim is defined in the *Energy Performance Directive for Buildings* legislation (EPBD) (European Parliament 2010). The need for specific definitions of NZEB tailored to each member state, culminating in the UK target for Zero Carbon Homes to be implemented in 2016.

The following sections (4.1.1-4.1.3) discuss the different legislation and legally binding targets applicable to EU member states and details the specific UK and Scottish context. The broad legislation areas are divided into the following areas; GHG reduction legislation (4.1.1) and renewable energy generation (4.1.2).

The legislation concerning building energy use, efficiency and renewables are discussed in a separate section (4.1.3). The remainder of the chapter (4.2) discusses the contemporary European low energy housing sector with the related UK (CSH) and Scottish legislation (S7) as well as other European alternatives.

4.1.1. Greenhouse Gasses & Carbon Emission Reduction Legislation

[Figure 39]

The current GHG Reduction legislation for the EU, UK and Scotland. Targets are shown from their originating documentation through curved lines. Legally binding targets are shown with a continuous line and suggested targets with a broken line. The EU legislation is in the top grey band with the UK in the middle and Scotland at the bottom.

4.1.1.1. Greenhouse Gas Reduction Legislation

Current GHG emission reduction legislation originated with the 1992 World Earth Summit in Rio de Janeiro. A non-legally binding treaty was formed which aimed to stabilize greenhouse gases in the atmosphere and to address the threat of global warming caused by these gasses (Wikipedia 2013a). This treaty set the foundations for the legally binding 1997 Kyoto Protocol to the United Nations Framework Convention on Climate Change (UNFCCC). As part of the Kyoto Protocol in 1997 the UNFCCC which includes 37 industrialised countries and the European Community committed to limit or reduce their emissions of greenhouse gases between 2008-2012 (8% reduction compared to 1990 collectively in Europe) as a basis for a long-term commitment to maintain the global temperature rise below 2 °C (United Nations 2008; UNFCCC 2012b; European Commission 2013; European Parliament 2010). Greenhouse gasses as defined by the Kyoto protocol are; *Carbon dioxide (CO₂); Methane (CH₄); Nitrous oxide (N₂O); Hydrofluorocarbons (HFCs); Perfluorocarbons (PFCs); Sulphur hexafluoride (SF₆)*(United Nations 2008). In response to the effects of climate change, the UK Government released the Stern Review in 2006 to determine the impact of global warming on the world economy. It is recognised as being one of the most widely known and discussed economic reports on climate change. It's key findings express that strong, early action on climate change (cost of 1% GDP, revised to 2% in 2008) outweigh the long-term costs (5% GDP per annum) and 5-6 degrees of temperature increase is a real possibility. The Stern Review received criticism for the lack of scientific evidence underpinning the findings, regarding the accuracy of the costs and the scale of temperature rises. Several outcomes of the report received positive critical response and action including the statement that calls for immediate strong action should be taken to reduce CO₂ (Stern 2006; Wikipedia 2013b). In 2008

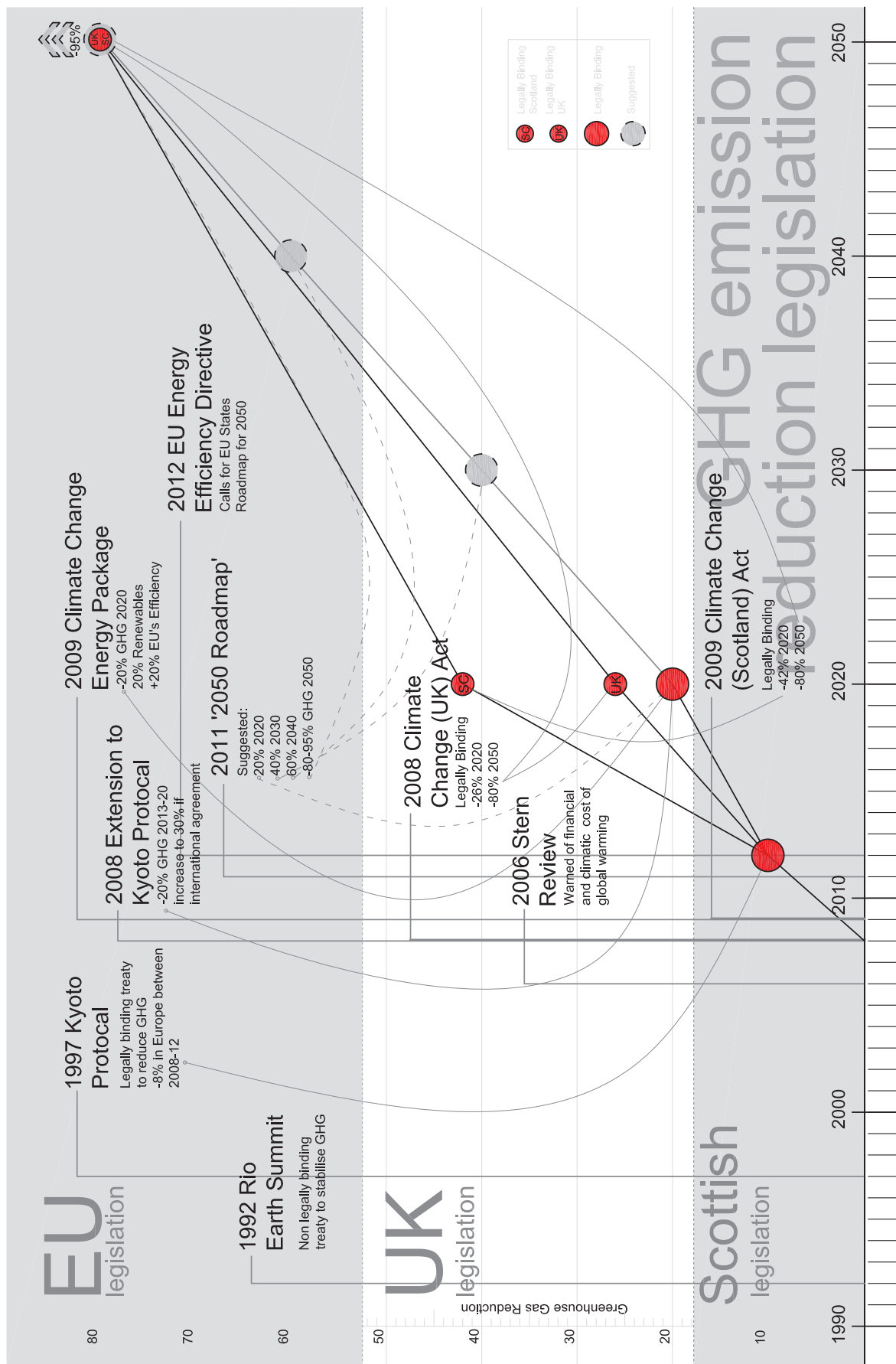


Figure 39- Greenhouse Gas Reduction Legislation Timeline

the European Community extended the Kyoto agreement and developed a legally binding commitment to achieve a 20% reduction in greenhouse gases between 2013-2020 (in comparison to 1990 levels), which will increase to 30% if there is an international commitment (European Commission 2010; UNFCCC 2012a). The EU only contributes slightly more than 10% of global emissions of GHG reinforcing the need for a global commitment (European Commission 2011a). Current European-specific carbon reduction targets originated with the 2009, EU Climate and Energy Package, which acts to ensure the EU meets its Kyoto agreement requirements for 2020. The key objectives are; 20% reduction in Greenhouse gases (compared to 1990), raising renewable energy generation to cover 20% of energy use, and a 20% reduction in energy use through a 20% improvement to the EU's overall energy efficiency (European Commission 2012b). In addition to meeting the Kyoto Protocol requirements, these targets were determined to secure energy supplies relying on less imported energy and more affordable prices which are crucial for growth, job creation and quality of life (European Commission 2011b). Further action taken by subsequent meetings of the UNFCCC, such as the publicised Conference of the Parties 15 (COP 15, 2009) in Copenhagen; produced little further binding international agreements to tackle climate change. COP 15 countries who account for around 80% of global emissions made significant pledges to cut their emissions. However, this will be insufficient to meet the 2°C climate change target, a statement that was subsequently agreed in the Conference of the Parties 16 (Cancun, 2010) (European Commission 2010; UNFCCC 2010).

In 2011 the European Council set a suggested objective of 80%-95% GHG emission reduction by 2050 by developed countries with recommended interim reductions of: 20% by 2020, 40% by 2030 and 60% by 2040 (compared to 1990 levels), (European Commission 2011a). The EU reconfirmed that a GHG reduction of 80-95% should be sufficient in order to keep climate change below +2 °C (taking into account necessary inter-governmental efforts from other countries; this will allow a global reduction of 50% in emissions by 2050). (European Commission 2011a). This EU 2050 target was later reinforced by the EU Energy Efficiency Directive (2012) placing an obligation on each EU member state to draw up a roadmap requiring that their entire building sector becomes more energy efficient by 2050 (commercial, public and private households included) (Tolbaru & euractiv.com 2012; European Parliament 2012).

In COP 18 (Doha, 2012) the Kyoto agreement was amended to include a second commitment period from 2013 to 2020 requiring an 18% reduction in GHG emissions (UNFCCC 2013). The targets for all countries are to be revisited in 2014 with the possibility of raising the target (Scottish Executive 2013c). Looking towards 2050 EU leaders have endorsed the objective of reducing Europe's GHG emissions by 80-95% and the EU commission have published a report; *"A roadmap for moving to a competitive low carbon economy in 2050"* which outlines a basic, cost effective way of achieving such reductions (European Commission 2011a). The EU targets for reductions in greenhouse gas emissions have called for more detailed, localised legislation specific to each member state in order for individual member states to meet their targets. Various independent research documents have been published at a more detailed European strategic scale to suggest practical routes to achieve the low-carbon economy defined in current European legislation. The research package; *"Road Map for 2050"* funded and published by the European Climate Foundation (ECF) by a consortium of experts including universities, sustainability consultants and architects aims to *"provide practical, independent and objective analysis of pathways to achieve a low-carbon economy in Europe"* (European Climate

Foundation 2010). This package is one of the most detailed, forward thinking documents available. The ECF's current research explores three main areas, low carbon Europe, a plausible way to meet the 80% reduction of target; decarbonising the power sector by 2030; and the questions and obstacles in the implementation generated by the initial Roadmap (European Climate Foundation 2013). The initial '*Road Map for 2050*' research provides facts mixed with inventive visuals presenting imaginative directions for the future of the European power sector. It urges near immediate and widespread actions are required to meet the 2050 targets. In addition to macro power generation, the research also considers reduction of energy demand in buildings to encourage efficient construction in both new buildings and retrofits. The research suggests that the current *"impact of energy savings policies will need to nearly triple from the current levels achieved by the EU energy efficiency package in order to achieve the EU's 20% by 2020"* (ibid)(European Climate Foundation 2010). This independent package of research illustrates the requirement for immediate action and revaluation of targets across all of the sectors covered in the energy saving policies.

4.1.1.2. UK Greenhouse Gas Reduction Legislation

The UK government has independent legislation to comply with its Climate Change agreements and EU targets. For compliance with the Kyoto agreement and European emission legislation the UK's legal GHG reduction target is 16% of total GHG emissions. This figure is the UK's contribution towards the EU target of minus 20% by 2020 (Europa 2011). The Kyoto agreement and EU target act as the foundation for UK GHG legislation and targets. However the UK government defined the world's first and most stringent legally binding emission reduction targets in the Climate Change Act (UK)(2008) (Legislation.gov.uk 2008; GOV.UK 2013f). The Act contains an increased (60% from the previous 2005 Bill) legally binding GHG reduction target of at least 80% (compared to 1990 baseline) by 2050. The Act enforces an intermediate reduction target of 26% of carbon emissions by 2020 which is an increase of 10% on the European target for the UK (House of Commons 2005; Legislation.gov.uk 2008; Boardman 2007). This increase has come from the UK's Department for Environment, Food and Rural Affairs (DEFRA) who stated that the interim reduction target in 2020 should be between 26-32% to ensure the 2050 target is met (DEFRA 2007). The Act aims to develop the UK as a low-carbon economy with targets exceeding the European legislation. The Carbon Plan sets out a more detailed overall strategy to meet these targets in each of the areas set out in the Act (GOV.UK 2011). The Climate Change Act combined with the overarching European legislation such as the EPBD and Climate and Energy Package has led to more specific legislative targets such as (net) Zero Carbon Homes by 2016 (2016/2017 if practical in Scotland) and renewable energy generation specific to each nation (Communities and Local Government 2009; Scottish Government 2007a).

4.1.1.3. Scottish Greenhouse Gas Reduction Legislation

Although Scotland shares the Climate Change Act (UK) targets it has a separate Climate Change Act (Scotland) (2009). The Act creates a nation specific, long-term framework '*intended to embed a more sustainable way of thinking and support investment in new technologies*' moving the public and private sectors towards a low-carbon economy (Scottish Government 2011c). The duties imposed by this Act place Scotland at the forefront of global efforts to tackle climate change (Scottish Government 2011c). Scotland aims to reduce

its GHG emissions by at least 80 per cent by 2050, equalling the UK's target. However, in 2009 it established more ambitious interim target of at least 42% emissions reductions by 2020, higher than the UK target of 26% and significantly higher than the UK's legal obligation of 16% (St. Andrew's House Scottish Government 2009a; Legislation.gov.uk 2008). However, it is stated in the Act that these targets can be varied based on advice from the UK Committee on Climate Change allowing for deviation from the targets. This creates flexibility allowing for adjustment if targets are unachievable without penalty. Scotland's current future targets (based on latest carbon data) against 1990 baseline figures are; 2015- 37%, 2020- 44%, 2025- 53% and 2027- 58% (Scottish Executive 2013c). These figures suggest a commitment to carbon saving above the level set in the Climate Change Act (Scotland)(2009). The Scottish Government supports moves to increase the EU's 2020 target from a 20% emission reduction to 30% (Scottish Executive 2013c). Scotland is currently top of the EU-15 league table for emission reductions between 1990-2011 with a reduction of 29.6% (European Environment Agency 2013).. The '*Climate Change (Scotland) Act*' along with the previously published 'Sullivan Report' has led to revisions to more specific legislation regarding carbon emission reduction in new buildings culminating in the aim that all new homes should be Zero Carbon by 2016/17 if practical (Scottish Government 2007a).

4.1.2. Renewable Energy Legislation and Targets

This section briefly outlines the current legislation and targets for Europe, the UK and Scotland.

4.1.2.1. European Renewable Legislation

In the move away from fossil fuels, electrical demand is likely to increase through reduction of electrical generation through gas and coal. The EU has developed legislation aiming to increase the electrical generation from renewables, which will have the knock-on effect of decreasing carbon emissions in this sector. The current renewable targets for Europe were outlined in the 2009, EU Climate and Energy Package (European Commission 2012b). The European Commission published a Directive stating that EU states should produce 20% of their energy from renewable sources by 2020 with individual targets. This aim originated from the 2007 Renewable Energy Roadmap (European Parliament 2009; Commission of the European Communities 2007; European Commission 2012a). The Directive also improves the legal framework to encourage the development of renewable energy sources. Since 2011, the EU had the world's largest regional energy market, serving 500 million people, it accounts for one-fifth of the world's energy use. The EU proposes to move to a low carbon economy amid concerns over long-term security and energy affordability; the strategy will have a greater reliance on electrical energy. Currently 45% of Europe's electrical energy comes from low carbon energy sources (including nuclear, hydropower), although these have limited lifespans which could mean up to a third of certain EU states will need to find alternative non-fossil fuel energy generation sources (European Commission 2011b). In order to provide a low carbon energy strategy with increased reliance on renewable energy there is a requirement for a significant increase in electrical renewable energy generation and further investment to the supply grid (European Commission 2011a). This investment will provide long-term energy security by reducing current bottlenecks in the renewable infrastructure, creating smart grids and improving existing energy distribution systems to

transport renewable energy from its source.

The Energy 2020 Discussion Document enforces that secure affordable energy supplies are crucial for growth, job creation and quality of life (European Commission 2011b). This document warns of the impact to factors if Europe becomes reliant on external energy generation. In order to achieve this security, the document calls for the development of a truly integrated internal (EU) market. It states that Europe has the resources and the knowledge to stay at the forefront of renewable energy generation and research but this will require continuing commitment and investment.

In 2011 the European Commission confirmed that the 2020 renewables target would be met if not exceeded, if the member states legislation is adhered to, estimating a possible saving of 10 billion Euros per annum (Commission of the European Communities 2011). In 2012 the previous allowable limit of 10% food based bio fuels, which was put in place in order to meet the renewable energy target, was further limited to 5% putting more pressure on other forms of renewable energy such as on-site generation (European Commission 2012a). This increased pressure may have led to the large demands on housing to offset the shortfall.

Non-legislative research reports have documented possibilities for long-term European Renewable Strategies to generate similar if not more radical approaches. The ECF Roadmap 2050 determines the increasing requirement for de-carbonisation of electrical energy generation focusing on the increased reliance of renewable sources (European Climate Foundation 2010). It estimates that electrical energy requirements are to increase by 80% in 2050 against 2005 levels due to the greater electrification of transport and of heating in buildings and industry.

Suggestions for wider scale, worldwide 100% renewable strategies proposed by third party organisations such as the World Wildlife Fund (WWF), ECOFYS and Office for Metropolitan Architecture (OMA) are published in the '*The Energy Report*' (WWF 2011). The report suggests that cleaner energy could be produced from an interconnected grid of renewable sources specific to each region across the globe, which follows similar suggestions to the legislative 'Energy 2020' European approach. The strategy involves using the world as an interconnected grid utilising all of the available sources of renewables and transporting it to where it is required. However, this strategy would require international agreements to provide global guidance and cooperation on renewable energy and efficiency efforts and has to be taken purely speculatively. The report highlights the scale of the task of creating a worldwide sustainable energy strategy, but also the possibilities if the strategies could be put in place.

4.1.2.2. UK Renewable Electrical Targets

In line with EU legislation the UK has legally binding targets for energy generation through renewables of 15% by 2020 as part of the 20% figure applicable to Europe as a whole (European Parliament 2009; Department of Energy and Climate Change 2011). In 2012 3.8% of the total UK energy demand was produced through renewable sources and 11% from electrical (from 9.4%, 2011). Based on these figures the Department of Energy and Climate Change (DECC) states that the UK is on course to meet the 2020 target (Department of Energy and Climate Change 2012d). DECC analysis shows that UK electrical demand is likely to increase by

30 to 100% by 2050 due to the shift towards electrical energy, a figure in line with EU estimates, however, currently there is no legally binding UK renewable energy target set for 2050.

4.1.2.3. Scottish Renewable Targets

Scotland has more defined, specific goals regarding electrical renewable energy targets. Scotland aims to produce 50% of Scottish electricity from renewables by 2015 and the equivalent of 100% of gross annual electricity consumption by 2020 (Scottish Government 2012f; Department of Energy and Climate Change 2012d). In 2011 it is estimated that 35% of Scotland's electricity came from renewable sources surpassing the target of 31% with various new large scale generation schemes operating (Department of Energy and Climate Change 2012d). Scotland also has measures in place to encourage small scale renewable energy generation discussed later in this section. The Scottish Government has defined that a 500MW of renewables should be in local or community ownership by 2020, 147MW of installed capacity was owned this way in 2011 which should increase with incentives such as the *Feed in Tariff* (FIT) (Department of Energy and Climate Change 2012d).

4.1.3. Building Energy Use and Efficiency

[Figure 40]

Current building CO₂ reduction targets legislation for the EU, UK and Scotland. Targets are shown from their originating documentation through curved lines. Legally binding targets are shown with a continuous line and suggested targets with a broken line. The development of low energy housing has become a critical issue in Europe over the last two decades in the struggle to reduce CO₂ emissions from buildings. The 2013 update on the Scottish ZCH makes the 2016/17 unclear however this diagram still retains the original target.

4.1.3.1. European Building Energy Use & the EPBD

Buildings are responsible for about 40% of the total primary energy use and for 36% of the CO₂ emissions in Europe (Economidou 2011; Europa 2009). The residential sector accounts for approximately 27% final energy requirements in Europe (Economidou 2011). Out of the 85-90% GHG target reduction (2050) the proposed proportion of GHG reductions targets in the residential sector of 88-91% by 2050 are the second highest proportion of reductions second only to the power sector to achieve 79-82% reduction by 2050 (European Commission 2011a). The European Commission published the (European) *Energy Performance of Buildings Directive* (EPBD) in 2002 to define an approach for GHG reduction. It is common legislation for European member states to cost-effectively promote the improvement of the energy performance of buildings (European Parliament 2003). The primary aim of the directive is to reach the EU climate and energy targets as defined in the Kyoto protocol. The recast EPBD document, (2010) aimed to make the goals more ambitious and to reinforce implementation of these goals. It allows for a closer following of the current EU policy to address energy performance of buildings rather than just carbon emissions reductions (Warren

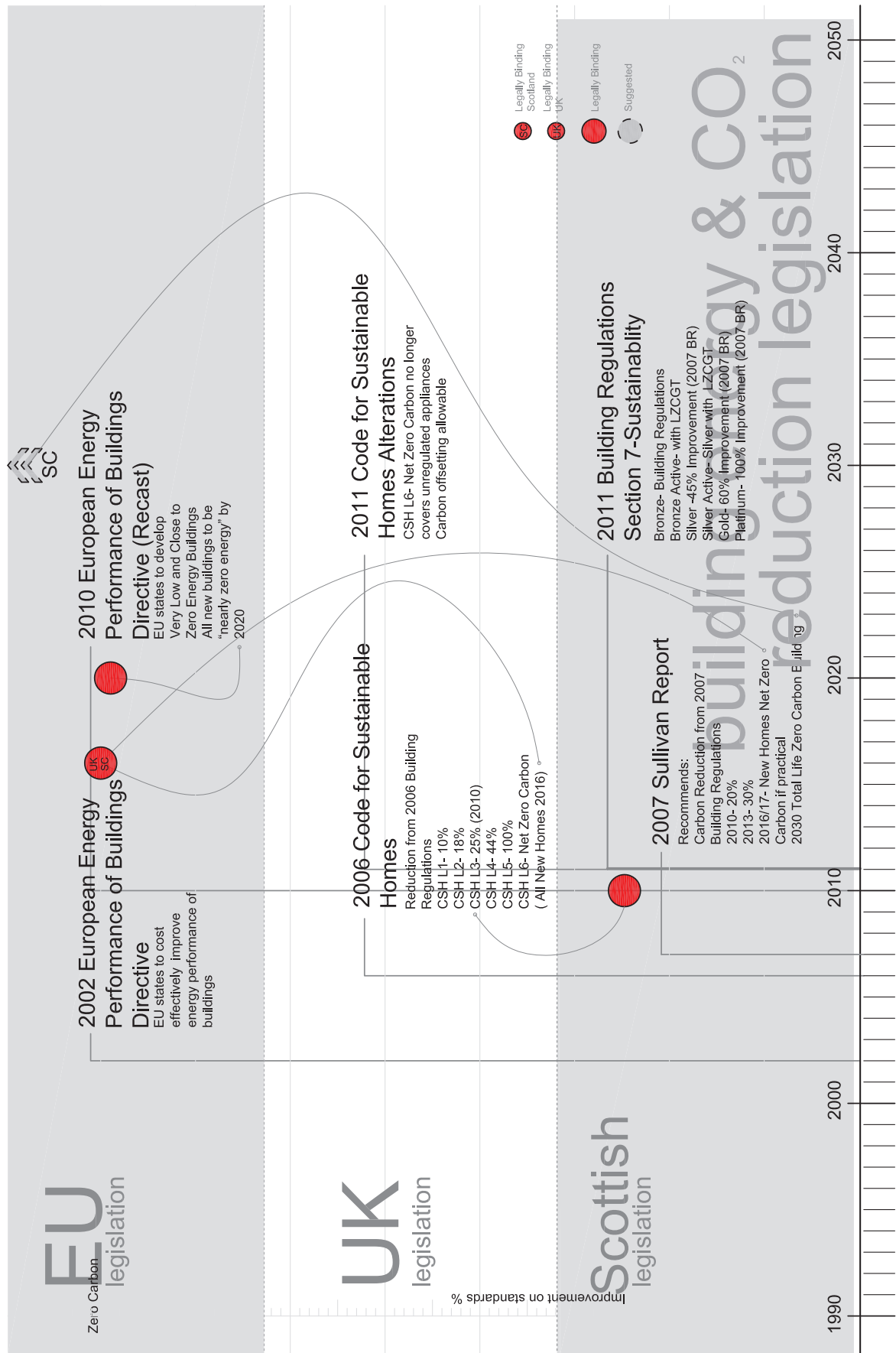


Figure 40- Building Energy Use and Efficiency Timeline

2011; European Parliament 2010). It suggests that EU Member States endorse national plans and targets in order to promote the uptake of very low and close to zero energy buildings. It sets a target for all new buildings to be “nearly zero energy” by 2020 with penalties for non-compliance and the aim of converging building standards across Europe (European Commission 2009). The directive defines ‘nearly zero energy building’ (NZEB) as a *“building that has a very high energy performance... energy required should be covered to a very significant extent by energy from renewable sources, including energy from renewable sources produced on-site or nearby”* (European Parliament 2010, p.18). The recast of the directive also defines the requirement of a *“detailed application in practice of the definition of nearly zero energy buildings, reflecting their national, regional or local conditions”* (European Parliament 2010, p.21). This calls for the Member States to create the specific methodology for national definition and implementation of NZEB that should respond to their climates and surroundings by 2020. Member States have sole responsibility for the minimum requirements for the energy performance of buildings and building elements. The minimum requirements should achieve a cost optimal balance between the investments involved and the energy costs saved. The calculation of the energy performance should *“be calculated on the basis of a methodology, which may be differentiated at national and regional level”* (*ibid*). These statements suggest a broad direction rather than European wide standards. An impact assessment that stated issues such as; higher costs (7%-15%), lack of trained professionals and low readiness of the construction industry would require tailored national specific approaches (Commission of the European Communities 2008; ECEEE 2011). The implications of these non-specific statements in the EPBD recast has led to many different interpretations of NZEB across the EU, some, which are specific to regional climates, and others which use national climates. This leads to more or less tailored solutions dependent on the sensitivity of the climate data and the climatic variation across the nations. The specific calculation methodologies, units and targets used also vary, making it very difficult for comparative analysis between nations (Jensen et al. 2009; Economidou 2011).

4.1.3.2. Other European Low Energy Approaches

There are many other concepts apart from ultra-low and energy efficient buildings which will cover different aspects and sustainability criteria use across the world. However, Passivhaus is the leading approach for the design and building of low energy buildings in the world with over tens of thousands of examples. Other approaches are generally more specific to individual countries and have few examples out with their home nation such as the Swiss standards ‘Minergie’, ‘Minergie –P’ and ‘Minergie-Eco’ (www.minergie.ch) and the German standards ‘Niedrigenergie’, ‘7-liter haus’, ‘4-liter-haus etc.’. Following the EPBD requirement for nearly zero energy buildings by the end of 2020 there are an extensive range of various zero energy concepts in the member states legislation. The approaches so far are included in the *Taking Stock and Looking Forward* document (Maldonado 2013).

4.1.3.3. UK Building Energy Use (Development of Legislation)

In 2011, the equivalent of 38.8 millions of tons of oil was consumed within the UK domestic sector (Department of Energy and Climate Change 2012b). This accounts for 28% of the total final energy

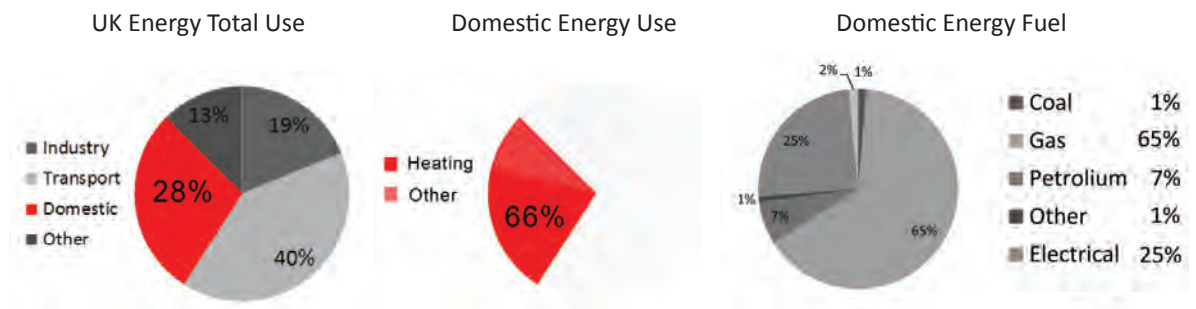


Figure 41 Energy Use UK (DECC, 2011)

consumption, 27% of CO₂ emissions, with 60% of this energy being used for space heating (Department of Energy and Climate Change 2012a; Department of Energy and Climate Change et al. 2011; RIBA 2009a) [Figure 41]. The average house emits nearly six tonnes of carbon a year, with dwellings built to modern standards emitting three tonnes, a large uninsulated, inefficiently heated dwelling could produce over 40 tonnes per annum (RIBA 2009a). The AECB calculate that the average house in 2006 used 278 kWh/(m²a) in total, with around 140 kWh/(m²a) used for space heating (AECB 2006). The space heating of homes represents 18.4% of the final total UK Energy consumption; therefore, the reduction of space heating requirements can have a major impact for GHG reduction targets [Figure 42]. The development of Bills and Acts from EU directives comes in the form of White Papers, two Energy White Papers were released in 2003 and 2007. The Energy White Paper (2003) references smart metering and performance certificates called for in the EPBD, the need for more efficient building fabric and services in building regulations and energy efficiency measures funded by the utilities (Department of Trade and Industry 2003; Boardman 2007). This paper addressed the need for a UK strategy to meet the Nearly Zero Energy Buildings by 2020 generated from the EPBD. This in turn produced the UK's Zero Carbon Homes Standard (ZCH). The second Energy White Paper (2007) further

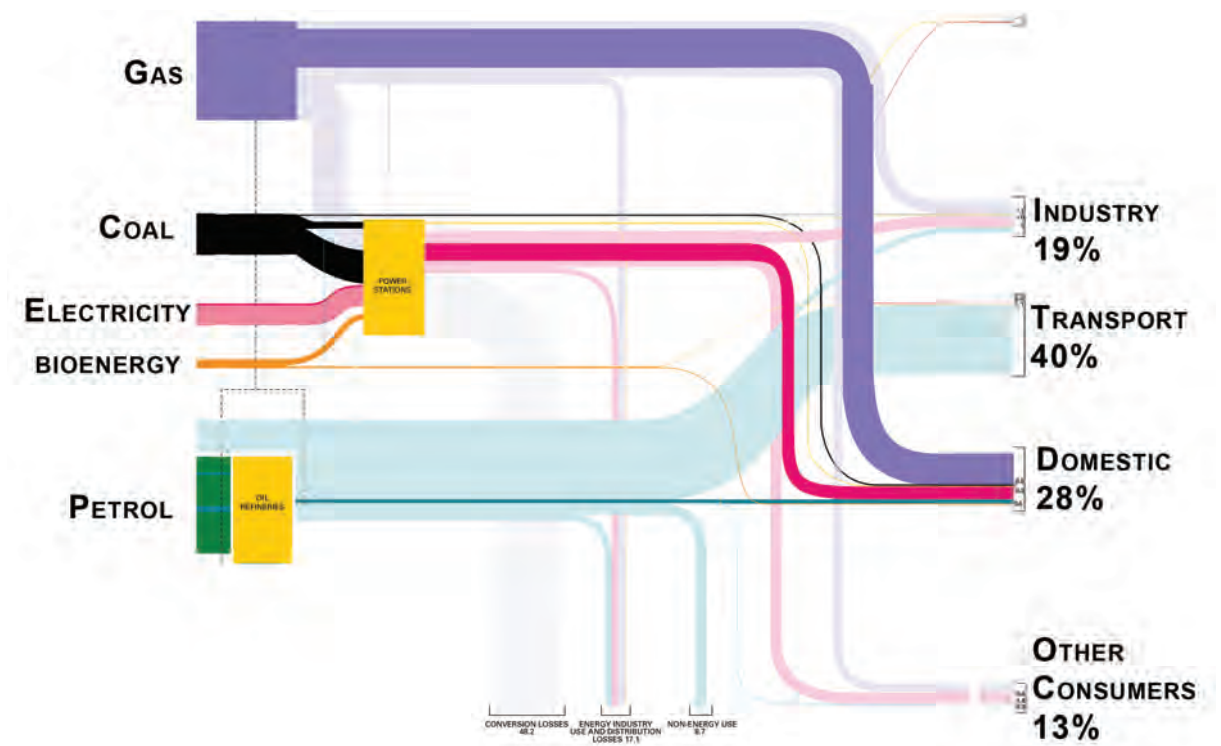


Figure 42- Energy Use by Fuel Source (DECC, 2011)

details the required actions of the EPBD; performance certificates; Zero Carbon Homes and improvements to existing housing and low- and zero carbon technologies from the utility suppliers which later developed into the Green Deal. The Government has acknowledged a study by DEFRA that states that household energy efficiency measures are more than four times more cost-effective per tonne of carbon saved than the next best demand-side sector, which is business (House of Commons 2007; Boardman 2007). In 2007 the “*Building a Greener Future*” policy statement announced that all new homes would be Zero Carbon (CSH L6) by 2016, later confirmed in the 2008 Budget (Communities and Local Government 2007). In February 2008 the Code for Sustainable Homes (level 6) definition of Zero Carbon was accepted by the Government (Communities and Local Government 2008b). This Zero Carbon Standard set one of the world’s most ambitious programmes in the new build residential sector in terms of renewable energy and carbon reduction. The Code for Sustainable Homes definition of Zero Carbon was questioned in the results of the December, 2008 consultation document which called for a detailed consolidation of how to achieve ambition Zero Carbon Homes and set a trajectory for doing so (Communities and Local Government 2008a). In subsequent re-drafts, the definition of a ZCH has since changed altering its status as a world leader in this area (Zero Carbon Hub 2010b). These alterations are discussed further in section 4.2.4. The 2011 ‘*Carbon Plan*’ summarises the Government’s intended detailed approaches to meet the requirements of the Climate Change Act (UK)(2008) and the EPBD introducing the mandatory use of Energy Performance Certificates (EPC), Green Deal financial system and smart energy meters (GOV.UK 2011). The plan also justifies the impact towards meeting 2050 GHG reduction targets of new ZCH (2016) stating that in the UK it is estimated that around a third of homes that will be occupied in 2050 are still to be built. Despite enforcing the importance of this, it does not state a deadline for the full introduction of the ZCH building standards. This is currently becoming a serious issue for the building sector as the new, conservation of fuel and power section of the building regulations (England, Part L) to come into operation in Autumn 2013 and are not currently published (May 2013) further holding up the development of the building industry to 2016 regulations (Harvey 2013).

4.1.3.4. Development of Scottish Domestic Energy Use

In 2002, Scotland’s energy use in residential sector represented 34% of the total energy demand that corresponded to 33% of CO₂ emissions making it the biggest contributor to CO₂ emissions in Scotland (WWF Scotland 2011). Unsurprisingly the energy use in Scotland differs from English and UK averages. Many areas in Scotland show a trend of higher than average energy consumption per capita (9000-10,000 kWh/m²) compared with the majority of England (>8000 kWh/m²). Scotland’s energy per capita use illustrates a national trend of higher energy consumption compared to much of England (Department of Energy and Climate Change 2012c). [Figure 43] This could be attributed to the increased heating requirement due to the less favourable climate and lower performing houses in rural areas and less gas connected houses (Skerratt et al. 2012; Scottish Executive 2012e; Scottish Executive 2011b). Moreover in Scotland the average CO₂ emissions in 2010 for rural dwellings was 8.4, while it was 5.1 for urban dwellings (Skerratt et al. 2012). Since 1970 until at least 2005 the proportion of space heating to other residential energy use has stayed constant at around 60% despite the improvement in building regulations and heating systems which aimed to increase

efficiency and reduce heat losses in new buildings. Scotland has moved away from a reliance of solid fuels in the 1970s to a 63% reliance on gas in 2005. Scotland uses the highest percentage of electricity for heating in the UK which reinforces the impact of the aim to generate 100% renewable electricity by 2020 (Utley & Shorrock 2008). The current targets regarding future domestic energy and carbon reductions developed primarily from the EPBD at a European level, then from the 'Low Carbon Building Standards Strategy for Scotland' (2007) and the 'Climate Change (Scotland) Act 2009' at a national level. These documents have started to create pathways towards introducing the basis of the framework for Zero Carbon houses by 2016/17 if appropriate within the Scottish Building Regulations Section 6-Energy & Section 7- Sustainability (Scottish Government 2007a; St. Andrew's House Scottish Government 2011c; Scottish Government 2011g). Current building standards are developing towards achieving ZCH with the introduction of different sustainability levels within Section 7, but the highest level; platinum is still to be fully defined. As of 2013 there is no clear definition of what 2016/17 energy standards in the Building Regulations (Section 6) will contain or any definition of definite specific strategies to achieve net Zero Carbon in new housing.

Map 2: Average domestic energy consumption per capita 2010 (kWh per capita)

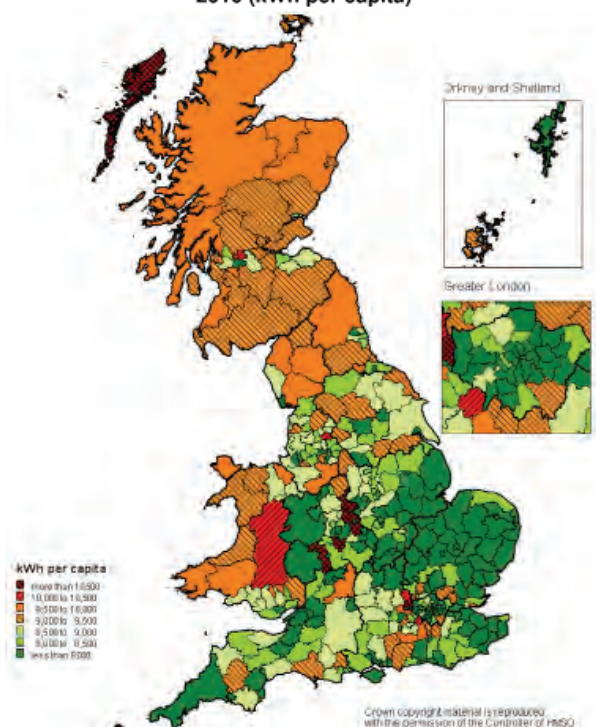


Figure 43- (Department of Energy and Climate Change 2012c)

4.1.3.5. UK Domestic Renewables

The EPBD recognises that in addition to reduced energy consumption, increased use of electrical energy from renewable sources are important to promote the security of the energy supply. It states that technological developments are *"creating opportunities for employment and regional development, in particular in rural areas"* (European Parliament 2010; Warren 2011). The EU Renewable Energy Directive 2009/28/EC states that member states should require a minimum level of renewable energy use in new buildings, implemented through building regulations or equivalent (Scottish Government 2013d, p.419). In response to this, the UK intends to use the future Building Standards and ZCH to enforce micro renewable electrical energy generation technologies or payment into carbon funds for similar technologies. The Climate Change (Scotland) Act 2009 encourages Scottish Ministers to promote energy efficiency, renewable heat and relaxed planning laws for air source heat pumps and micro-energy generating equipment (St. Andrew's House Scottish Government 2009a). UK wide incentives such as the Feed in Tariff (FIT), Green Deal and Renewable Heating Incentive (RHI) aim to encourage the uptake and help with the affordability of new and existing domestic on-site micro renewable generation, which will aid the Governments renewables target by encouraging widespread use of micro generation (GOV.UK 2013e; Communities and Local Government 2009; GOV.UK 2013d)

Electricity & Feed In Tariff

Statistics state that in 2011 almost 40% of the total electrical energy generated in the UK is used in the domestic sector with the possibilities for saving in this sector being significant at UK level (Department of Energy and Climate Change et al. 2011; GOV.UK 2013b). The FIT aims to encourage small scale energy generation projects at an individual and community level to produce renewable electricity, thus reducing the load on national generation and the national grid, increasing onsite renewable energy generation and potentially improving the security of the energy supply by creating micro power stations. Launched in 2010, the FIT incentive pays fixed amount for each unit (kWh) of electrical energy generated through renewable means such as; PV, hydroelectricity and wind turbines (GOV.UK 2013d). As well as payment for electrical energy generated, extra units generated can be exported back to their electricity supplier for a higher fee. Depending on the date of installation and tariff given, homeowners are able to pay off the initial cost of PV arrays in relatively short period, allowing for a net profit for future energy generated. The current impact on national energy generation of the FIT is small despite a large number of FIT installations, over 205,000. In 2011, 498.2GWh was reported as being generated under the UK Feed in Tariff scheme, from 206,851 installations, this represents around 0.19% of the total UK (266922GWh) and 0.47% of total domestic electrical energy use (GOV.UK 2013c; GOV.UK 2013b). The majority of generation comes from PV (52%), second to wind at 19%, with 14% Anaerobic Digestion and 10% from hydro. The majority of the PV installations are retro fitted domestic arrays of less than 4KW producing 35% of the total FIT energy generation. Almost a fifth of the generated electricity was exported off site, with PV generation providing 79% of the exports (GOV.UK 2013c).

Green Deal

Launched in 2013, the Green Deal funds the upfront costs for energy saving improvements including renewable energy technologies allowing the homeowner to pay off the balance in monthly instalments through the electricity bill (GOV.UK 2013e). The key idea of the Green Deal is to encourage energy efficiency improvements, paid for by savings from the householders energy bills. Any energy saving improvement debts outstanding stay with the house rather than the homeowner.

UK Renewable Heating

In addition to renewable energy generation initiatives, the UK Government has a Renewable Heat Incentive (RHI) programme. The 2012 document *'The Future of Heating A strategic framework for low carbon heat in the UK'* determines the scale of the domestic heating requirement and the reasoning for the RHI, stating that the heat demand from buildings was 540TWh (third of UK energy demand) in 2009, with 409TWh demand from the domestic sector. Of this 409TWh 307TWh was for space-heating with the majority of the fuel used to meet this demand was gas (Department of Energy and Climate Change 2012a; GOV.UK 2012, p.26). The RHI is the world's first long-term financial support programme for renewable heat. Launched in 2011 for the non-domestic sector, with the domestic sector due in spring 2014, the RHI pays participants that generate and use renewable energy to heat their buildings. The scheme supports installations of the following technologies

certified by the Micro Generation Certification Scheme installed after 2009; air source heat pumps that heat water, biomass boilers, ground source heat pumps and solar thermal systems. The scheme also offers subsidies to cover the cost of installing renewable heating systems. *‘By increasing the generation of heat from renewable energy sources (instead of fossil fuels), the RHI helps the UK reduce greenhouse gas emissions and meet targets for reducing climate change’* (GOV.UK 2013g). The Scottish Government has a target for the equivalent of 11% of heat demand to come from renewable sources by 2020. Steady progress is being made, with the latest figure of 3.8% in 2011 showing an increase of more than 35% from the previous year (Department of Energy and Climate Change 2012d). The long-term strategy of the RHI is to increase the use and reduce the cost of renewable heat, however, it expects gas to be the dominant fuel supply for heat until around 2030 (Department of Energy and Climate Change 2012d).

4.2. Low Energy Housing Approaches and Legislation

4.2.1. European Approaches for Ultra-low Energy Building and NZEB

Across Europe, there are many variations in building regulations and energy efficiency legislations generated from the Kyoto Agreement and the *Energy Performance of Buildings Directive* (EPBD). The 2010 recast EPBD calls for NZED by 2050 however, each member state defines their own targets, methods and energy performance assessment methodologies; making comparison of different standards very difficult (European Parliament 2010). A survey in 2011 identified 23 European descriptions for high performance buildings including; *low-energy house, high-performance house, passive house (Passivhaus), zero-carbon house (ZCH), zero-energy house, energy-savings house, green building, energy-positive house, eco house, 3-liter house, and ultra-low energy house* (Kibert & Fard 2012; Erhorn-Kluttig & Erhorn 2011). Erhorn-Kluttig & Erhorn state that the terms relate to one of the three categories; low energy consumption, low emissions or sustainable/green aspects. These descriptions all have different calculation methodologies and targets underpinning them. Therefore determining a widely accepted meaning is challenging. In the most basic terms a *nearly zero energy building* (NZEB) will combine renewable energy and very low energy in its description. Various reports exist that attempt this comparison, both within Europe and Worldwide. The Zero Carbon Hub’s Compendium and ‘Europe’s Buildings under the Microscope’ serve as the clearest comparisons between European Standards (Zero Carbon Hub 2010b; Economidou 2011). A report published by the European Commission; *‘Building Energy Performance under the EPBD, Taking Stock and Looking Forward’* states current progress from EU member states towards NZEB in 2020 (Maldonado 2013). To define building fabric performance levels many countries use maximum u-values and minimum air tightness level (specification backstops) some also specify maximum permissible thermal bridging to reduce heat losses through inefficient detailing. These figures relate to the countries specific climates and are therefore not comparable. The Scottish Government published a series of research papers comparing Scottish standards with a range of Nordic counterparts but also stated comparison was not possible (Scottish Executive 2008c; Scottish Executive 2008b). The majority of the European nations use a target kWh/(m²a) for space heat energy requirements and some use EPC ratings (Economidou 2011; Maldonado 2013). Nevertheless, the UK is the only country to use kilograms of CO₂ emissions as the main units for building performance analysis

(*ibid*). Despite most of the counties using the same units of measurement for NZEB they employ different methodologies and have a series of other factors required to meet regulations and future regulations. The leading low energy concepts such as Minergie and Passivhaus determine a maximum space heating demand (kWh/(m²a)) in addition to other stipulations such as MVHR, improved detailing, minimum u-values, and maximum air infiltration (Porteous 2009).

4.2.2. UK Legislation for Zero Carbon Housing Overview

[Figure 44]

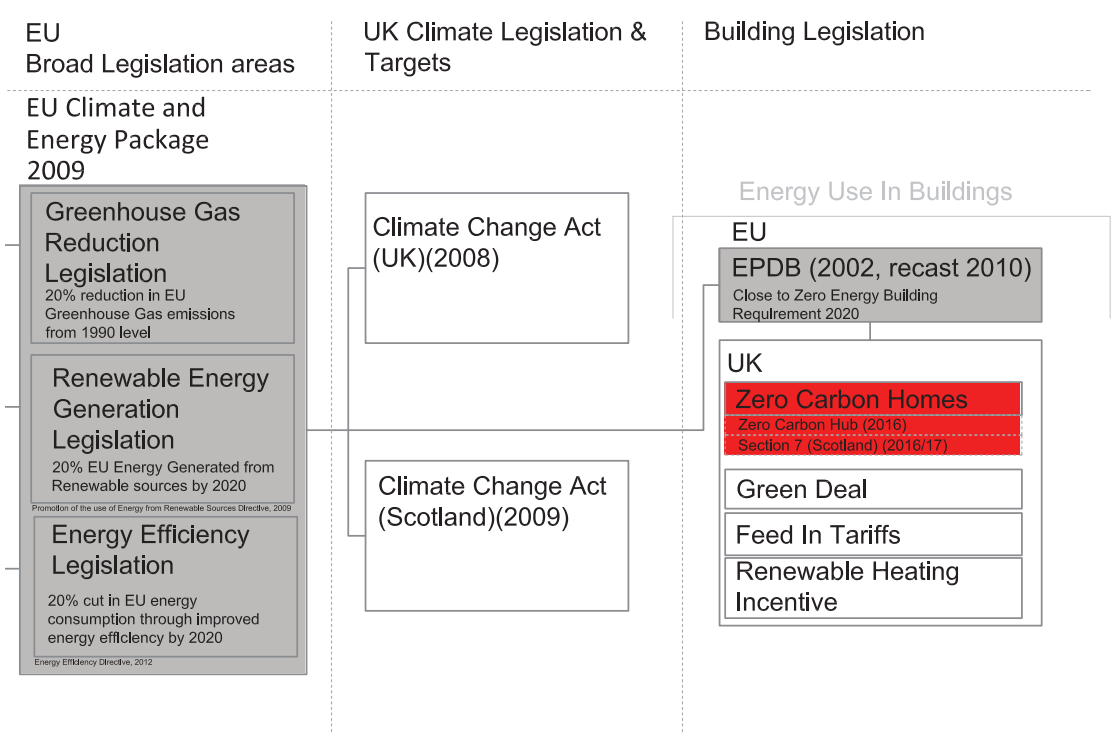


Figure 44- UK ZCH Legislation Drivers

Illustrates the origins of Zero Carbon Homes and the legislation that actions it in each of the UK nations.

The UK employs different climate change legislation, low carbon strategies and building standards legislation across its nations, each Government employs different variations of similar legislation. The legislation is primarily generated by European targets for energy efficiency, carbon dioxide emission reduction and energy use within buildings. Other documents have influenced current legislation such as the 1998 Egan Report which led to significant attempts to improve the efficiency and quality of housing through *Modern Methods of Construction* (MMC)(Communities and Local Government 2004).

The UK shares some climate change and carbon emission documentation such as the Stern Review, Climate Change (UK) Act and various incentive programs (FIT, Green Deal, Renewable Heating Incentive). However, building standards and related carbon emission regulations have documents and legislation specific to different nations within the UK (Stern 2006; Legislation.gov.uk 2008; GOV.UK 2013d; GOV.UK 2013e; GOV.UK 2013g). For England and Wales ZCH by 2016 was introduced through the 2007 '*Building a Greener*

Future policy statement'(Communities and Local Government 2007). The Zero Carbon Housing criteria for the UK has changed numerous times since 2007, the carbon saving criteria was formally defined by CSH level 6 (Communities and Local Government 2009). The current definition is generated by the Zero Carbon Hub (Zero Carbon Hub 2013c). The majority of the English Building regulations and targets (Part L) were traditionally shared with Wales but, in 2011 the Welsh Ministers gained control over Building Regulations in Wales (BRE 2012).

Scotland has its own more specific Climate Change Bill and ZCH legislation. The 2007 '*Low Carbon Building Standards Strategy for Scotland*' (Sullivan Report) (Scottish Government 2007a) defining ZCH by 2016/17 if appropriate. This target is beginning to be detailed within current Scottish building regulations Section 6 & 7, defining similar targets to England and Wales (St. Andrew's House Scottish Government 2009a; Scottish Government 2012e; Scottish Government 2011g; St. Andrew's House Scottish Government 2011c).

4.2.3. Zero Carbon Homes England and Wales

In response to the European EPBD aim of promoting the uptake of very low and close to zero energy buildings (all new buildings 'nearly zero energy' by the end of 2020, 2010 recast) the UK Government published a policy statement in 2007: '*Building a Greener Future*' (European Parliament 2003; Communities and Local Government 2007). The document stated that all new homes should be Zero Carbon by 2016 (England and Wales) adopting the BRE's Code for Sustainable Homes Level 6 (CSH L6) definition of Zero Carbon (carbon performance) to become mandatory in the 2016 Building Regulations standards (Communities and Local Government 2007; Communities and Local Government 2009). This target and definition was recognised as one of the most ambitious worldwide national standards programmes in the practice of mandatory, low energy housing targets (Zero Carbon Hub 2010b). In the years subsequent to the introduction of the original definition of Zero Carbon Homes, legislation has significantly altered since its introduction in 2007.

4.2.3.1. Zero Carbon Homes Definition Progression

In 2007 the '*Building a Greener Future*' document, the UK government stated that using the CSH was voluntary but would become a mandatory sustainability rating system for all new build houses in England, Wales and Northern Ireland. The intention was that the CSH Level 6 (net zero carbon) carbon saving level would be included in the 2016 Building Regulations therefore mandatory for all new homes (Communities and Local Government 2009). The CSH covers a range of environmental issues such as water, waste and materials, whilst the mandatory Building Regulations standards proposed in 2007 would only relate to carbon performance element (Communities and Local Government 2007). The CSH L6 and UK Zero Carbon Homes definition originally aimed to provide all energy requirements (emissions from space heating, ventilation, hot water and fixed lighting and expected energy use from appliances) for the house through wholly on-site means therefore reaching Zero Carbon status. This means that exports and imports of energy from the development (and directly connected energy installations) to and from centralised energy networks, the building will have net Zero Carbon emissions over the course of a year (Communities and Local Government 2007).

The future carbon reduction levels in building standards were proposed as(Communities and Local Government 2007);

- 2010- 25% Carbon saving over 2006 standards (Part L)- CSH L3 Carbon Performance
- 2013- 44% Carbon saving over 2006 standards (Part L)- CSH L4 Carbon Performance
- 2016- Zero Carbon- CSH L6 Carbon Performance

It allows housing to become a net generator of energy to the grid, balancing low-carbon energy demand and supply through renewable generation. The proposed method aimed to provide a contribution to the UK's national carbon reduction requirements without adversely inflating the costs of house construction. This on-site generation approach could have been developed because moving away from fossil fuels to renewable electrical generation as the main form of energy significantly increases demand on the electrical supply grid. Transporting renewable forms of energy long distances is inefficient and requires a substantial investment in infrastructure. The UK's initial approach ZCH to use either on-site renewable electricity generation or for community or localised energy generation eases this demand (Communities and Local Government 2009). However, the cost effectiveness of this approach was questioned in the same year by Banfill and Peacock due to the cost of localised energy generation for all of the houses electrical energy use (Banfill & Peacock 2007).

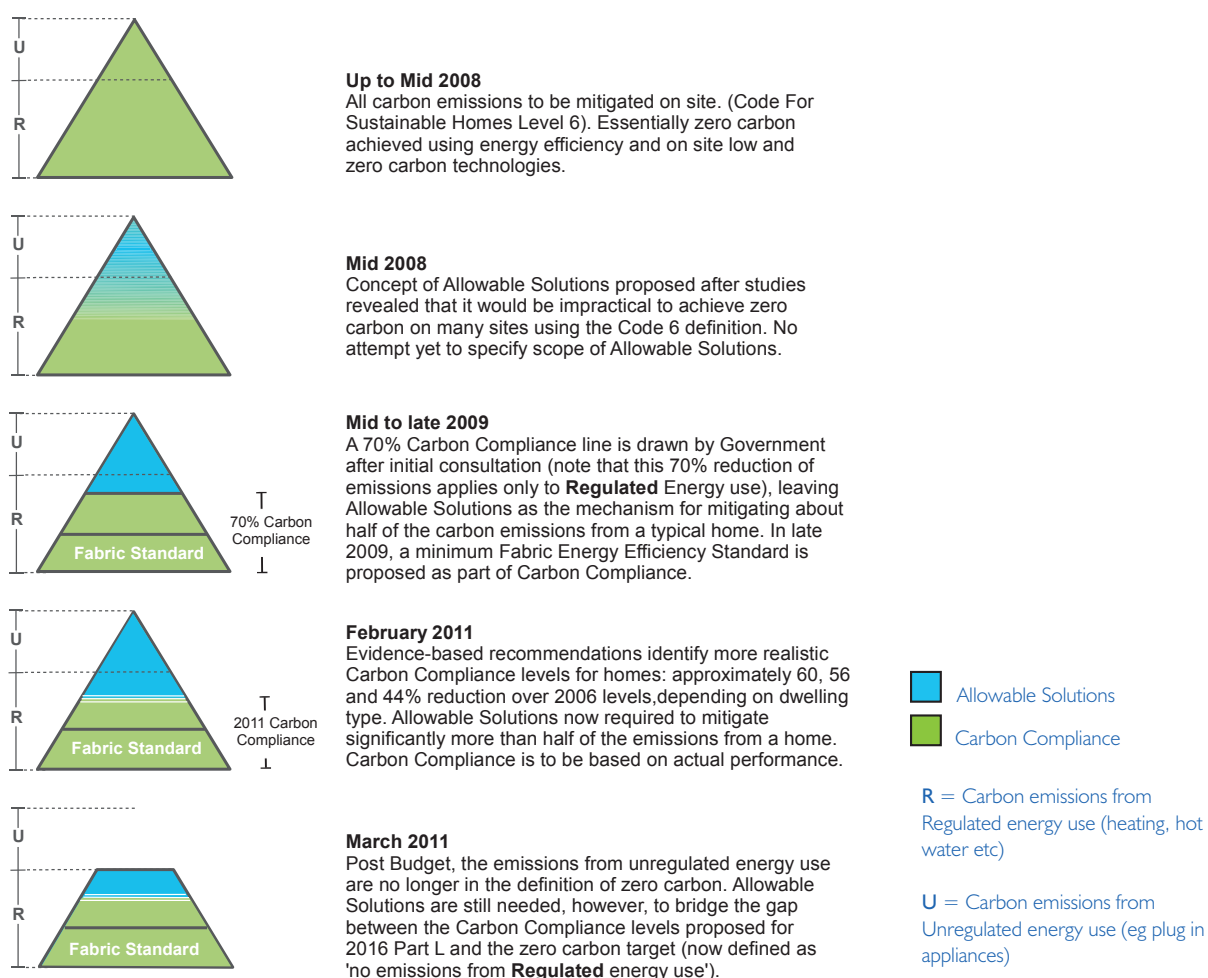


Figure 45- Changing Definitions of ZCH Until 2011 (Zero Carbon Hub & Marjewycz 2011)

Alterations to Initial Definition

Since 2008 the Government guidance states that there are no plans to make CSH mandatory at a national level, the current 2016 Zero Carbon policy and the 2016 Zero Carbon target now determines the requirement for Zero Carbon Homes (Kougionis & Zero Carbon Hub 2013; GOV.UK 2013a). After 2008 the Zero Carbon Hub superseded CSH and became the Government's advisory board responsible for developing a workable definition for Zero Carbon new homes. All of the recommendations including backstop specifications and specific aims regarding energy requirements for the ZCH definition are generated from Zero Carbon Hub research papers (Zero Carbon Hub 2009b; Zero Carbon Hub & Marjewycz 2011).

Zero Carbon Hub Definitions

[Figure 45] Illustrates the various changes of the zero carbon definition (England and Wales) showing the introduction of carbon offsetting (Allowable Solutions) and the removal of emissions from unregulated sources.

Off-site Carbon Reductions- Allowable Solutions

The first major change to Zero Carbon definition was in mid-2008 with the departure from the CSH definition and the introduction of Allowable Solutions concept. The concept allowed for carbon emissions to be accounted for off-site, it was proposed due to series of studies which revealed it was impractical to achieve Zero Carbon through entirely on-site renewables, a conclusion reinforced by previous comment from the UK Green Building Council (Zero Carbon Hub & Marjewycz 2011). However, the definition of Allowable Solutions (off-site solutions) remained ambiguous until 2011 (Zero Carbon Hub & Marjewycz 2011). In June 2011 'Allowable Solutions' were defined as carbon-saving projects funded by the housing developers. This system aimed to offset the on-site carbon compliance deficits (Zero Carbon Hub & Marjewycz 2011). It is unclear if the carbon-saving projects need apply to the specific development that funded them. The most recent definition is discussed below.

Carbon Compliance

[Figure 46]

To determine the scale of carbon reduction accounted for by Allowable Solutions the Carbon Compliance concept was introduced in 2009. Carbon Compliance determines a minimal on-site carbon saving figure using Allowable Solutions (off-site) to bridge the gap to meet the (net) Zero Carbon emission status.

The 2009 Carbon Compliance target was set at a

minimum of 70% of the energy used for heating, cooling, lighting and low or Zero Carbon technologies with the remaining 30% Allowable Solutions Bridging the gap to Zero Carbon (Zero Carbon Hub 2010a). This figure was revised in February 2011 to a percentage (56%-detached houses, 44% flats) reduction over 2006 levels

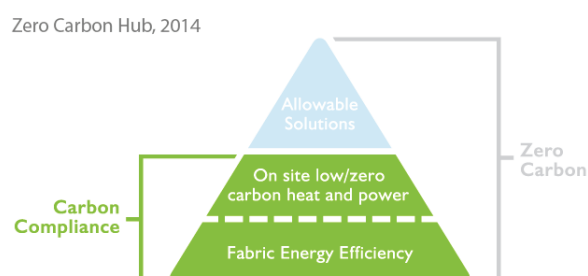


Figure 46 Carbon Compliance

dependant on building type (Zero Carbon Hub & Marjewycz 2011).

This translates into recommended carbon emission levels of (Zero Carbon Hub 2014b):

- 10 kg CO₂(eq)/m²/year for detached houses.
- 11 kg CO₂(eq)/m²/year for attached houses.
- 14 kg CO₂(eq)/m²/year for low rise apartment blocks (up to 4 storeys).

Unregulated resources

The most significant changes to the Zero Carbon definition came in the March 2011 budget with the exemption of energy from unregulated energy use (appliances) from the carbon calculation. This significantly reduced the energy requirement from on-site renewables or *Allowable Solutions*.

ZCH Minimum Fabric Energy Efficiency Standard Definition (FEES)

[Figure 47]

In late 2009 Zero Carbon Hub proposed a recommendation for a minimum Fabric Energy Efficiency Standard (FEES) suggesting minimum u-values, fabric specification and space heating/cooling demand in Zero Carbon housing (Zero Carbon Hub 2009a). The FEES are defined as; 39 kWh/m²/year for apartments, mid/end terrace & semi-detached and 46 kWh/m²/year for detached dwellings. A typical u-value for the building elements has been

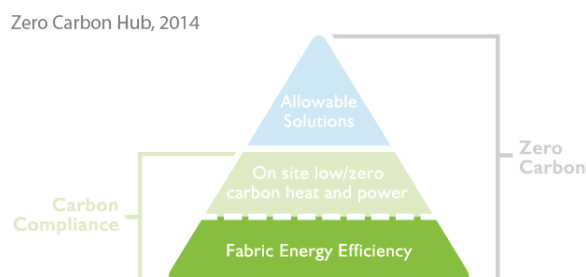


Figure 47- FEES

defined by the Zero Carbon Hub to allow the construction industry to see the impact to the future standard (Zero Carbon Hub 2012). The two targets are to encourage similar wall specification across the different typologies, the variation reflects the higher proportion of exposed surface area therefore greater heat loss in a detached housing typology (Zero Carbon Hub 2012). The FEES that Zero Carbon Hub proposes falls short of the already successfully implemented Passivhaus standard that determines a maximum SSHD of 15 kWh/(m²a) irrespective of dwelling type (Passivhaus Institut 2007; Mead & Brylewski 2012). Therefore heat lost through the built fabric can be greater (using FEES) thus requiring more energy production to generate heat. For ZCH this will require more on-site energy generation and carbon offsetting through Allowable Solutions. The Zero Carbon Hub states that Passivhaus performance is 25-30 kWh/(m²a) depending on dwelling type despite Passivhaus key criteria is a SSHD of less than 15 kWh/(m²a) irrespective of dwelling type (Zero Carbon Hub 2009a, p.66). It is stated that this anomaly is due to the FEES calculation convention (Zero Carbon Hub 2013c, p.11). This may also be attributed to the use of a static 'Passivhaus' fabric being used within the SAP methodology using generic climate data rather than a dynamic, design and climate specific Passivhaus specification calculated through the Passivhaus' PHPP methodology. In addition, this specification does not call for the same rigorous checklist criteria of Passivhaus which may lead to higher energy use than estimated and a reduction in quality.

Zero Carbon Hub Defined Routes

[Figure 48]

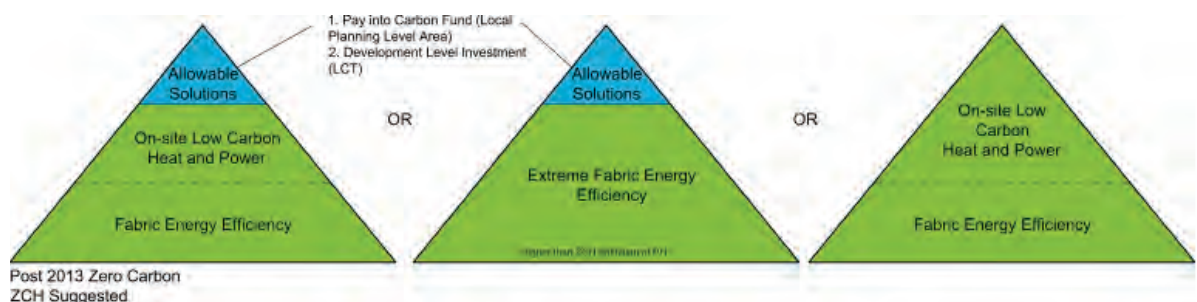
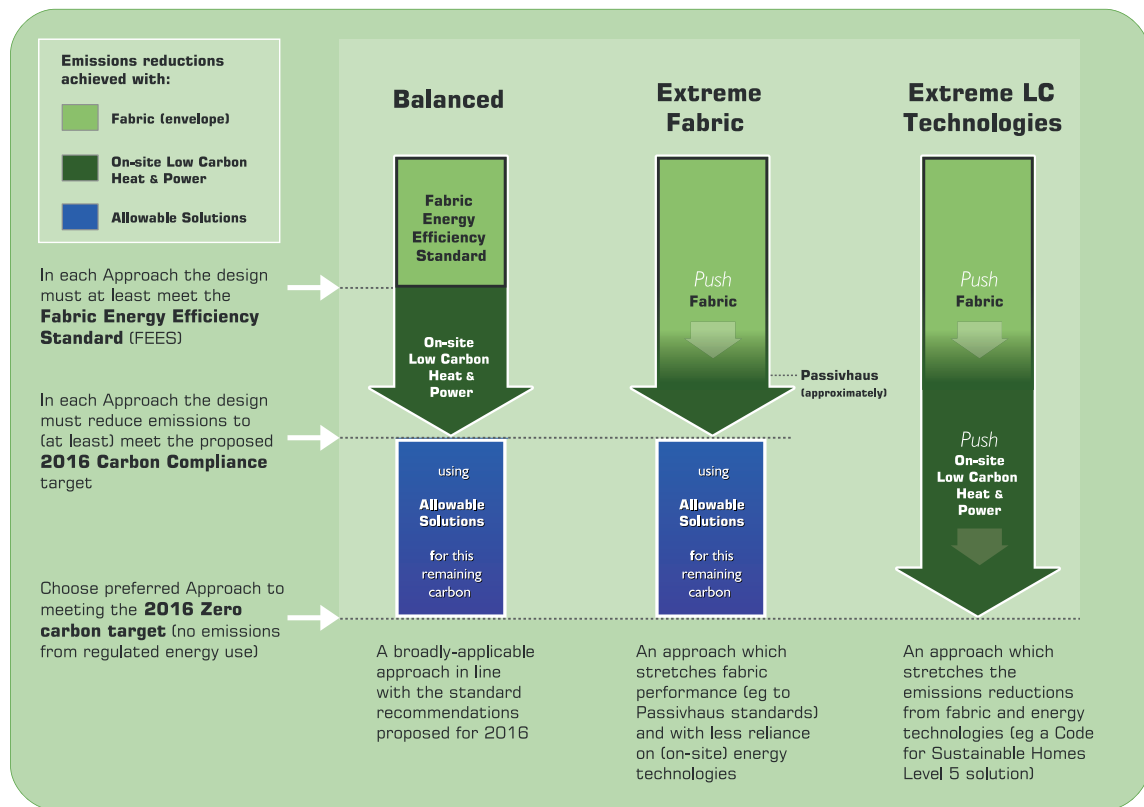


Figure 48- Approaches to ZCH (Zero Carbon Hub 2013c, P9)

In 2013 the Zero Carbon Hub defined the most comprehensive definition of Zero Carbon that integrated Allowable Solutions in conjunction with the FEES in the “Zero Carbon Strategies for Tomorrow’s New Homes” report (Zero Carbon Hub 2013c). The report suggests three possible routes to Zero Carbon which are; Balanced, Extreme Fabric and Extreme Low Carbon Technologies (with Extreme Fabric) (Zero Carbon Hub 2013c);

- The balanced strategy integrates the FEES, on-site low carbon heat & power and Allowable Solutions.
- The extreme fabric strategy negates the use of on-site low carbon heat and power and instead focuses on the fabric and integrated low carbon solutions. The extreme fabric approach is

indicated to the above Passivhaus standard.

- Extreme low carbon technologies strategy utilises this extreme fabric performance but also a greater proportion of on-site low carbon heating power in the balance strategy, this is the closest strategy to the initial Zero Carbon homes legislation.

Allowable Solutions 2013

[Figure 49]

Allowable Solutions will allow for the remainder of “carbon emissions not cost-effectively off-set on-site” to be “tackled through nearby or remote measures” (Zero Carbon Hub 2014a). The definition and implementation method of Allowable Solutions is still under consultation as of November 2013

(Zero Carbon Hub 2013a). The 2013 applications of

Allowable Solutions are; the developers pay into a carbon fund with the intention that local authorities make use of these funds for low carbon projects, the second is to invest in carbon saving project within the same development such as a district heating scheme (Zero Carbon Hub 2013c). One of the possible significant issues with *Allowable Solutions*, particularly with the first method is that the end-user may not receive much in the way of energy saving benefits due to the Allowable Solutions being used to fund a project not affecting the development. The current definition is a major departure from the strategy originally defined in the original CSH L6 (net) Zero Carbon target and is still under a state of change and consultation (Communities and Local Government 2008b; Zero Carbon Hub 2013c). The exact definition of *Allowable Solutions* is still undergoing consultation as of 2014 (Zero Carbon Hub 2014d). Ultimately there is a European requirement due to the EPBD recast for all buildings to be NZEB by the end of 2020 so the eventual definition of zero carbon (or better) will have to adhere to this target.

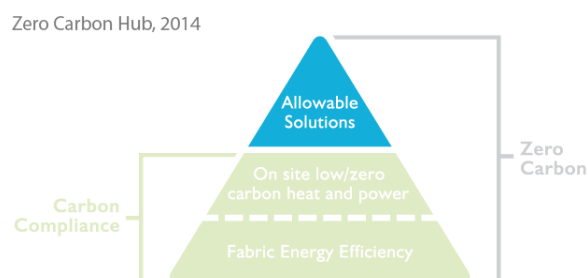


Figure 49- Allowable Solutions- Carbon Offsetting

Costs

‘Cost Analysis: Meeting the Zero Carbon Standard’ document suggests the most cost effective method of achieving ZCH for 2016 as a house that uses solar PV as a significant carbon reduction technology. This house uses an efficient gas boiler, the minimum fabric efficiency standard (FEES), Allowable Solutions (AS) and PV. All of the costs are based on an increase from 2013 standards.

“The following cost allowances are considered to be reasonable for achieving the proposed Zero Carbon Standard (Zero Carbon Hub 2014c)”:

- Detached homes = ~£6,700-7,500
- Semi-detached and mid-terraced properties = ~£3,700-4,700
- Apartments (low-rise) = ~£2,200-2,400

The report discounts the advanced approach that uses a close to Passivhaus fabric efficiency standard as

unlikely to “...outstrip the cost reductions projected for solar PV” due to the expected “greater scope for efficiency improvements and associated cost reductions with PV technologies than in insulation or window products ...therefore it is assumed to continue to be a more expensive option in terms of capital costs” (Zero Carbon Hub 2014c, p.7).

4.2.3.2. Code for Sustainable Homes (CSH)

[Figure 50]

Despite CSH not being mandatory it is still defined as the independently accredited government endorsed sustainability rating for new residential development (GOV.UK 2013a). Code for Sustainable Homes (CSH), first introduced by BRE in December 2006 came into effect on the 10th of April 2007 (adopted by the Welsh Assembly Government (WAG) in May 2008), and was intended to serve as a guide for future building regulations in England. When first introduced as part of legislation it was recognised as one of the most ambitious programmes out of all worldwide national standards for the practice of low energy housing. It determined the aspirational target and method for achieving carbon saving in the proposed Zero Carbon new homes. The CSH standard assessment levels were made mandatory from May 2008, but there was no mandatory minimum level, meaning that there was no requirement to design and build a home to meet the standards set out in the Code, however, new homes would be assessed against the CSH levels. This status has now changed and CSH is not mandatory unless a local authority includes it as a requirement in the local planning requirements or where public sector (Homes and Communities Agency) funding is involved (Kougionis & Zero Carbon Hub 2013; BREEAM 2013a). It is a broad ranging Sustainability Standard rather than an approach aimed solely to reduce space heating and carbon dioxide emissions to a minimum. The intention of using CSH L6 was to provide the industry with an indication of future building regulations towards 2016. The CSH is a development of the BRE's Ecohomes rating scheme first developed in 2000 (BREEAM 2013b). The CSH is the “national standard for the sustainable design and construction of new homes which it aims to reduce carbon emissions and promote higher standards of sustainable design above the current minimum standards set out by the building regulations” (GOV.UK 2013a). The code has nine measures of sustainable design. Each of the nine categories has different weightings. The energy and CO₂ emissions have a clear priority in terms of points available. However, due to only some of the issues being mandatory



Figure 50- Kingspan\ Potton's Lighthouse First CSH L6 House (Potton, 2009)

there is flexibility to select issues to respond to. This is particularly true in lower levels of the code with less mandatory elements. The nine measures are;

- Energy Use / CO₂ emissions
- Water
- Materials
- Surface water run-off (flooding and flood prevention)
- Waste
- Pollution
- Health and well-being
- Management
- Ecology

Within nine categories there are separate 34 issues, each assessed against environmental performance at design stage and post construction using objective criteria and verification. It uses a 1 to 6 level system to rate the overall sustainability performance of a new home, each of which has mandatory carbon dioxide emissions standards. Reduction in carbon dioxide emissions compared with Building Regulations, Part L (2006) and the original proposal dates (Communities and Local Government 2007);

- CSH Level 1-10%
- CSH Level 2-18%
- CSH Level 3-25% (originally proposed for 2010)
- CSH Level 4-44% (originally proposed for 2013)
- CSH Level 5-100%
- CSH Level 6-Net Zero Carbon (originally proposed for 2016)

Many of the “Zero Carbon” (CSH L6), solutions built such as the ‘Lighthouse’ (Potton, 2009) require technical solutions rather than super insulated envelopes (Passive Haus) to achieve the required standard due to CSH energy requirements. Current CSH homes statistics- Between April 2007 and March 2012, 54,976 dwellings at post-construction stage received a three star rating and 142 dwellings received a six star rating (Department for Communities and Local Government 2012).

As of March 2014 a policy paper questions the future of CSH as the Zero Carbon Homes definition now comes under the control of the Zero Carbon Hub (GOV.UK 2014).

4.2.3.3. English Regulations & Standards

The Building Regulations set the current and near future standards for buildings. The English Building Regulations are in 14 ‘parts’, Part L is the section that covers conservation of fuel and power, and therefore carbon emissions (BRE 2012). Part L of the building regulations define the minimum requirements for building performance (DER and TER), unlike many low carbon standards which are expressed in terms of improvements over the minimum requirements. See 2.4.7 Scottish Building Standards Section 6 for more details on DER and TER which is a shared calculation methodology across the UK. The future English building

regulations will action the minimum requirements that are suggested by the Zero Carbon Hub for Zero Carbon Homes.

4.2.3.4. Other UK Standards

There are other standards and approaches developed in the UK for low energy with various levels of use. The Energy Saving Trust (EST) is a government funded body that promote energy efficiency to householders (RIBA 2009a). The EST defined the UK best practice in 2005, with a standard much higher than building regulations. It takes some elements from Passivhaus standard such as SSHD, Power units, airtightness, MVHR, low u-values. It represents a 60% improvement on building regulations; however, the assessment procedure uses the SAP methodology rather than the PHI's PHPP (Energy Saving Trust 2005; RIBA 2009b). This use of the SAP methodology is to retain compliance with the building regulations, as PHPP is not recognised as a valid calculation methodology for compliance.

Another approach is the AECB CarbonLite standards which are separated into Silver standard, Passivhaus standard and Gold standard. The standards uses Passivhaus and PHPP as part of their methodology, they also define a standard above Passivhaus defining (gold); lower primary energy demand of 58 kWh/(m²a) and CO₂ emissions of 4 kg/m²a and integration of energy generation systems, solar hot water, A-rated appliances (AECB 2007; AECB 2013b; AECB 2013c). Similarly to Passivhaus it is not a government endorsed standard or part of legislation. However, there is a certification process for quality assurance that uses the PHI or the 'Low Energy Building Website' (AECB 2013a).

The BRE has its own Environmental Assessment Method, BREEAM (BRE Environmental Assessment Method) which is a voluntary measurement rating for green buildings, established in the UK but used worldwide. It addresses '*wide-ranging environmental and sustainability issues*' rather than being a fabric performance standard (BRE 2013a). The BRE state that BREEAM is applicable for all building types, however, for residential types, the use of CSH is encouraged (BREEAM 2013c).

These to date have had little use in residential projects with the legislative standards and Passivhaus concept seeing widespread use throughout the UK.

4.2.4. Scottish Zero Carbon Homes and Building Standards Legislation

Under devolved powers, Scotland has alternative building standards to the rest of the UK with a different structure and different targets that reflect varied construction trends and a generally harsher climate. Published in December 2007, the '*Low Carbon Building Standards Strategy for Scotland*' (LCBSSS, The Sullivan Report) defined the future Scottish standpoint for the development of Low and Zero Carbon Building strategies in response to the EDPB's requirement for NZEB by the end of 2020. In August 2009 Scotland published its own national climate change legislation: Climate Change (Scotland) Act, it shares the UK's 80% reduction target for CO₂ emissions by 2050, However, Scotland has more stringent targets than the UK with interim targets including a 42% (UK 26%) reduction of CO₂ by 2020 (St. Andrew's House Scottish Government 2009a). The Act legally changed legislation in order to action some recommendations made in the LCBSSS. The most ambitious aim from the LCBSSS is to have all new buildings "*Net Zero Carbon*"

by 2016/17 if practical with an aspirational aim of “*total life Zero Carbon*” buildings by 2030 (Scottish Government 2007a). These low carbon building legislation targets are implemented by staged improvement to the Scottish Building Standards Section 6-Energy and the implementation and continued development of Section 7-Sustainability. Scotland’s current domestic low carbon legislation uses the SAP methodology to calculate heating energy demands and carbon compliance. This methodology generates energy performance rating for the building, which will in turn determine if the building meets current regulatory requirements. Future legislation such as Zero Carbon homes also use this methodology for testing compliance. The SAP methodology is discussed further in 4.3.



Figure 51- A Low Carbon Building Standards Strategy for Scotland (Scottish Government 2007a)

4.2.4.1. Scottish Zero Carbon Homes Development

[Figure 51]

‘A Low Carbon Building Standards Strategy for Scotland’(LCBSSS), published in 2007 defines a plan for the development to low carbon building standards strategy, therefore the future direction for the Scottish building sector. The LCBSSS was the initial document defining the target of zero carbon buildings Scotland. In 2007, 24,500 new houses were being built per year and more than 40% of Scotland’s carbon emissions came from the heating and lighting of buildings, justifying the possible implications of a low carbon building sector (Scottish Government 2007a). The report offers greater certainty regarding future regulations to developers and other stakeholders in the building industry to invest in the relevant skills and to exceed the current

minimum standards and achieve future standards. Existing buildings are not covered within the scope of the report and it is stated that the housing owners should take responsibility for 'steady and consistent' improvement over the next ten years. Various document and initiatives are being implemented to raise the standard of existing housing to improve efficiency and eliminate fuel poverty (more than 10 per cent of their household income spend on fuel) (as far as practicable) by 2016 in order to meet the targets defined in the Climate Change (Scotland) Act and by Scotland's Sustainable Housing Strategy (Scottish Executive 2002; Scottish Executive 2013g; Energy Saving Trust 2013; Scottish Executive 2012f). This is implemented by various programs such as the Home Energy Efficiency Programmes for Scotland (HEEPS) which gives energy advice and financial assistance to make exiting homes more efficient (Energy Saving Trust 2013). The most ambitious outcomes of the report is the target of Net Zero Carbon buildings by 2016/17 if practical and the possibility of total Life Zero Carbon Buildings by 2030. It calls for a *"transformation of the construction industry so it can deliver low, very low and zero carbon, climate change adaptable buildings at minimum social and economic cost and risk* (Scottish Government 2007a, p.19)". In order to achieve the ZCH target by 2016/17 and the 2030 ambition, the Sullivan report suggests the following staged carbon saving target relating to carbon saving for domestic buildings to be implemented through relevant sections and revisions of the Scottish Building Standards:-

- 2007- Base Building Standards
- 2010- 30% Carbon saving over 2007 standards
- 2013- 60% Carbon saving over 2007 standards
- 2016/17- 100% Carbon saving over 2007 standards (net Zero Carbon)
- 2030- Ambition of Total Life Zero Carbon Buildings

The current Scottish definition of net Zero Carbon defined in LCBSSS accounts for space and water heating, lighting and ventilation, discounting unregulated appliances (Scottish Government 2007a, p.p7). The definition for the Total Life Zero Carbon Buildings aspirational target is: *"the building should be responsible for net zero carbon emissions over its entire life, including construction (the embodied energy of building materials), use, maintenance and finally, demolition"* (Scottish Government 2007a, p.16). In order to develop a low carbon building standards strategy the report defined 56 recommendations, separated into nine work streams, which define the implementation of the targets stated above, the requirement for more research into specific low energy topics and consideration into altering standards and legislation. The work streams are (Scottish Government 2007a, p.19);

- 1 Performance in Practice
- 2 Raising Standards
- 3 Existing Non-domestic Buildings
- 4 Existing Domestic Buildings
- 5 Low Carbon Equipment
- 6 Process
- 7 Compliance

- 8 Energy Performance of Buildings Directive
- 9 Costing

Requirement for Research

The majority of recommendations for research are within the policy area of Building Standards Division (BSD) (Scottish Government 2011e). The LCBSSS stated that there is a gap between as designed, as built and as managed energy performance. Other key issues raised in the report consider alternative European models of energy saving and building standards. The report considers the use of the Passivhaus energy concept in Scottish legislation. However, one of the European members of the Sullivan panel states that legislation could not impose the necessary living habits (MVHR) on the dwelling user and to realise the enhanced energy performance and to avoid mould growth arising from condensation, the occupants must be prepared to adjust (Scottish Government 2007a, p.18). The LCBSSS suggests that further consideration into effects on occupant behaviour and comfort are required (See section 2.4.8 for further details). The LCBSSS considers the implementation of backstop u-values and airtightness for building fabrics by 2010 to match Nordic countries but states that consideration must be taken into social and financial implications, which require further research. The report queries the cost effectiveness of the 2007 Scottish Planning Policy, Renewable Energy (SSP6) requirement for onsite and low carbon equipment without first implementing energy efficiency measures (Scottish Executive 2007).

Impact and Progress since the LCBSSS

Since 2007 recommendations made in the report, there have been a number of new research documents, legislative documents and amendments to legislation. Since 2009, Scotland's Climate Change Act has introduced various targets regarding GHG emission reduction, amendments to the Planning Act and various research documents (See Section 2.4.1). The legal act that enforces the planning system is the 'Town and Country Planning (Scotland) Act, the 2009 revision includes sections that aim to reduce GHG emissions as a result of the 'Climate Change (Scotland) Act 2009', Section 72 and suggestions made in the LCBSSS (Legislation.gov.uk 1997, p.(3F)). The amendment aims to *"ensure that all new buildings avoid a specified and rising proportion of the projected greenhouse gas emission... through the installation and operation of low and zero carbon generating technologies"*. The 2009 version of the planning act superseded the criticised Scottish Planning Policy, Renewable Energy (SSP6) following the LCBSSS recommendations.

The Sullivan report panel created an update on the fifty six recommendations from the LCBSSS; 'Progress Report on the Low Carbon Building Standards Strategy for Scotland' released in January 2011 (Scottish Government 2011e). The progress report states that despite the economic downturn in 2008 the suggested 2010 improvements in carbon emission reductions targets were to be enforced in the Scottish building regulations and reconfirmed the intention of net ZCH by 2016/17 (Scottish Government 2011e). The progress report confirmed that the suggested 30% Carbon saving over 2007 standards was implemented on time within the 2010 building standards. In May 2011, a new section was introduced into the Building Standards Section 7. This covers Sustainability with the Bronze standard stating mandatory practice. Sustainability Labelling relating to the Section 7 levels for all new buildings was made mandatory at this time (see 'Section

7, Building Standards' later in this chapter for details), a system similar to the sustainability levels of CSH relating to sustainability features and carbon saving.

In the four years following the LCBSSS, many of the recommendations have been addressed by 'Building Standards Division' through the 'Building Standards Advisory Committee, 2008 Energy', 'Compliance Working Parties' and the 'Climate Change (Scotland) Act 2009'. The Scottish Government has also developed detailed Low Carbon reports on; energy efficiency, economic strategies and future policies (Scottish Government 2011b; S. A. H. Scottish Government 2009b; Scottish Government 2010). 'A Low Carbon Economic Strategy for Scotland' confirms Scotland's ambition of net zero carbon new buildings from 2016/17 (Scottish Government 2010a).

LCBSSS Recommendations Interpretation

The Sullivan report highlighted many issues concerning moving to a low carbon economy. These recommendations on the whole interpreted as a requirement for further research. However, the research questions, in many cases have taken a certain interpretation of the recommendation that misses the overriding point such as:

"Consideration of 'Passivhaus' performance and its effect on occupant behaviour and comfort" (Scottish Government 2007a, p.11).

No conclusive consideration of Passivhaus and its suitability for Scottish occupants has been performed in relation to the LCBSSS. Instead a study comparing the calculation methodologies was performed by Strathclyde University (Tuohy & Langdon 2009)

"Research to understand better why there is a gap between 'as designed', 'as built' and 'as managed' energy performance" (Scottish Government 2007a, p.11).

The outcome of this recommendation led to a specific approach to the research, attributing blame to the variance between accredited drawings and as built construction. The Zero Carbon Hub is also currently performing a research study to determine the Performance Gap, seeking stakeholders views and experience (Zero Carbon Hub 2014d).

The performance gap between as designed and as built energy consumption is a well-known problem. *"There is a noted gap between designed and as-built performance in the UK, that fabric heat loss can be 100% more than that predicted by design"* (Zero Carbon Hub 2013b).

There are numerous reasons for a performance gap, however, the first stage in the process, the calculation methodology appears to be fundamentally flawed. The SAP methodology uses UK average climate data to estimate energy performance (BRE 2011a, p.2012). SAP will display the same energy use and energy cost (using identical building prototypes) for a building located in central Glasgow and a building located in Kirkwall (Orkney), therefore ignoring the significant differences in latitude and climate.

Research and its Influence on Standards

Since 2007 a substantial body of research has been published including national level research and also alternative standards and approaches from Europe. The BSD considered the possibility of the 'as designed' and 'as built' energy performance gap being attributed to the construction of some buildings not following approved drawings. However, it determined, this was perceived by stakeholders with further evidence being required to collate factual data (Scottish Executive 2010b).

A key report comparing Passivhaus and UK regulations compared 2007 Building Standards with three levels of further energy efficiency measures, Passivhaus and two AECB standards with SAP and PHPP: 'Passivhaus, CarbonLite and the Passiv House Planning Package (PHPP) calculation method' (Tuohy & Langdon 2009; Scottish Government 2011e). The objective of this project was to undertake PHPP calculations and comparisons with Passivhaus and CarbonLite criteria, the report provided an approximate comparison between the proposed energy standards and useful space heating energy (Scottish Government 2011e, p.21). Further work on PHPP calculations and Passivhaus and CarbonLite has been undertaken by the Energy Systems Research Unit of the University of Strathclyde. The 2011 comparison report stated that *'opportunities to consider occupant behaviour and comfort in a UK context are only now being presented, as Passivhaus projects in Scotland and the rest of the UK are developed and taken to completion'* (Scottish Government 2011e, p.21).

Building Standards

A significant amount of research comparing Scottish building standards and fabric efficiency to Nordic counterparts was performed and published in two documents. The 2009 research document; *'International comparison of energy standards in building regulations: Denmark, Finland, Norway, Scotland and Sweden'* concluded that that the Scottish building standards are not equivalent to the Nordic countries due to the colder climates (Scottish Government & BRE 2009). Other countries all use a limit on space heat demand measured in kWh/m² or a limit on elemental U-values rather than a carbon reduction target (kg CO₂/m²/annum) to determine energy requirements within their regulations. The different countries do, however, use broadly similar calculation methodologies following the principles set out in the applicable European standards. The study uses the UK's SAP methodology and a 3 bedroom prototype house. It demonstrates that if the Scotland used Swedish U-values, airtightness and MVHR CO₂ emissions could be reduced by 13-19% (on 2010 standards). Lowest allowable u-values or backstops are used as indication of building fabric performance. The *'Assessing the Costs of Nordic Domestic Energy'* report builds on the previous research (above) and assesses the cost implications of implementing various combinations of insulation and ventilation values and LCT based on backstop and typical levels from Denmark, Norway, Finland, and Sweden to assess CO₂ emissions. The study also quantifies the effect of the addition of various low and zero carbon technologies to achieve a target of 30% carbon reduction. The key findings of the research were improvement to the built fabric (using Nordic backstops) could only achieve an 17% reduction when using typical Swedish fabric values (natural ventilation) with only a 3.4% cost increase (Scottish Executive & Langdon 2009, p.48). The report also appears to suggest that the cost implications of using MVHR are not cost effective with a carbon emission reduction of 15.2% costing 6.5% more than the Scottish baseline (Scottish Executive & Langdon 2009, p.48) Only a biomass boiler and a high capacity wind turbine could

meet the 30% carbon reduction target with no fabric improvement. It was agreed that the improved u-values could be achieved with more insulation or a new design approach with non-standard specifications. However, some contractors highlighted issues such as extra costs and technical risks of using new details (Scottish Executive & Langdon 2009). As a result of the research report backstop levels of U-values and guidance on airtightness have been improved for the 2010 energy standards for both new domestic and non-domestic buildings. Guidance has been updated to provide ventilation solutions, including mechanical ventilation and heat (Scottish Government 2011e).

A Working Group (formed in 2011) review future standards, analysing responses from consultations held before standards are introduced generates limited research documents. However none of this material has the comprehensive direction and level of detail found in the Zero Carbon Hub documentation (Scottish Government 2012b; Scott & Scottish Government 2013). It was also stated in 2011 progress report that despite the economic downturn it should not influence the long-term goals of net zero carbon buildings. The LCBSSS continues to be the principle document which is the basis for review and improvement of the domestic energy standards, unlike the UK Government's external body (Zero Carbon Hub) that has led to continually updated definitions of ZCH through multiple documents and announcements (Scott & Scottish Government 2013).

Zero Carbon Definition Scotland

The current definition of Scottish Zero Carbon Homes is less developed than the rest of the UK. The most detailed direction for Scotland's Zero Carbon Homes is found in the current Building Standards section 6 and 7 and the limited research documents. However, the highest sustainability target (Platinum, Section 7) of the building standards is incomplete with only the first aspect out of eight is defined: 'Emission Rate (DER) is to be 100% lower than the Target Emission Rate (TER) set by the 2010 Standards. To establish this, the DER should not exceed zero (This net zero carbon equivalent is a 100% improvement on the 2007 Standards) (Scottish Government 2013d). The Zero Carbon Hub is responsible for developing a definition and to deliver zero carbon homes on behalf of UK Government, the hub also releases consultation documents defining each part of the definition. However, this research is not applicable to Scotland and there is no single external body responsible for the ZCH definition and delivery in Scotland. The majority of the research is performed within the Scottish Government or associated bodies. The original 2007 and current definition of net Zero Carbon housing planned to account only for regulated carbon emissions; space and water heating, lighting and ventilation regarding carbon emissions defined in the LCBSSS. This definition for ZCH is one that the national UK Government implemented after March 2011. Technical details regarding Scotland's low and zero carbon definition are discussed in 4.2.7.

Sullivan Report 2013 and Section 6/7 Update

The requirement for rural housing with lower running costs has significantly increased due to; rising fuel prices, lack of gas connection, generally more harsh weather conditions and higher levels of fuel poverty. The new build building regulations call for more efficient housing. However, recommended changes to 2013 regulations (60% reduction in carbon emissions over 2007 standards) have been pushed back to 2015 the

regulations until the change will retain the 2010 figure of 30% carbon reduction (Scottish Government 2007a; Scottish Executive 2013a). This will have the knock on effect of having approximately 30,000 extra houses producing more CO₂ emissions than planned at a strategic level in 2007. This also puts the target of ZCH in Scotland by 2016/17 into question. The 2013 update on the LCBSSS states that their 'level of ambition has not changed' but does not state the 2016/17 zero carbon aim still exists (Scottish Executive 2013a).

Alterations to Zero Carbon Targets

Due to the economic downturn, recent publications suggested the 2013 improvement to Section 6 (Energy and carbon saving) will not be fully introduced until 2014 (Scottish Government 2011e). The lack of recommended performance increase in the 2013 standards will put greater pressure on the industry to rapidly improve carbon saving measures if the 2016/17 target is to be met. In 2012 it was announced that the Sullivan Panel was to reconvene in May 2013 with calls being made for the panel to reevaluate Scotland's position on Low and Zero carbon homes (Scottish Executive 2013d). The details of the meeting state a revision of the 2016/17 target but do not outline the revision. The focus is reinforcement of the aim of NZEB houses from 2020 which related to the European requirement from the EPDB (Scottish Executive 2013a). There is also no mention of the aspirational goal of Total Life Zero Carbon Buildings by 2030 which was stated in the original document.

4.2.4.2. Scottish Building Regulations Structure and Section 6, Energy

The Scottish Building Standards act as the documentation to define targets and the technical specification to achieve carbon saving targets applicable in buildings. The Building Scotland Act (2003) is the legal act that enforces the Building Standards, amended for each revision to the Building Standards. Since 2011 in Scotland, Building Standards are split into sections 0-7 covering Structure, Fire, Environment, Safety, Noise, Energy and Sustainability (Scottish Executive 2011c; BRE 2012). The low and zero carbon aims are mainly implemented within Section 6 (Energy) and Section 7 (Sustainability).

The enforcement of the Energy section 6 of building standards targets is primarily to increase energy efficiency and reduce carbon emissions by '*ensuring that effective measures for the conservation of fuel and power are incorporated dwellings and buildings consisting of dwellings*' (Scottish Government 2013d, p.360). Improvements to Section 6 will '*result in a greater need to consider the benefits which localised or building-integrated low carbon equipment (LCE) (e.g. photovoltaics, solar water heating, combined heat and power and heat pumps) can make towards meeting standards*' (ibid). Through lowering of carbon dioxide emissions the impact on the rising cost of fuel and energy will be minimised. After research suggested by the 'Sullivan Report' the decision has been made that the Building Standards should continue to use backstops values (i.e. maximum U-values and airtightness, minimum efficiencies of heating and cooling equipment etc.) as the method of defining a fabric efficiency standard along with carbon emissions for 2010 (Scottish Government & BRE 2009; Scottish Government 2011e, p.22). Along with the fabric 'backstops' calculation, results used for assessing the compliance of domestic buildings with Standard 6.1 are expressed in kilograms of carbon per square metre of floor area per year (kgCO₂/m²/annum) resulting from heating, ventilation (if mechanical),

domestic hot water and lighting rather than the more commonly used space heat demand kWh/(m²a) (kilo-Watt hours per meters squared floor area per annum) and Specific Primary Energy Demand (kWh/(m²a)). In accordance with 2002 EPBD the predicted level of carbon emissions is calculated through Standard Assessment Procedure (SAP), the Government approved methodology for the energy rating of dwellings. This emission level is defined as the Dwelling (Carbon) Emission Rate (DER) (European Parliament 2003; Scottish Executive & Langdon 2009). SAP also produces a Target (Carbon) Emission Rate (TER) which is a the target CO₂ emissions rate of a notional building (i.e. a dwelling of the same size, shape and 'living area fraction' as the proposed dwelling), calculated using a fuel packages table found in 6.1.2 of the current Technical Handbook (Scottish Executive 2013h; Scottish Executive & Langdon 2009). The RIBA states that *'TER the calculated emissions rate is adjusted by a fuel factor that raises the emissions target if the proposed dwelling uses a more carbon intensive fuel (e.g. grid electricity for heating). The TER is then reduced by 20%-28% over the minimum building standards* (Improvement Service 2011, p.19). *This means that to comply with this criterion an electrically heated dwelling will require more insulation (or other energy efficiency measures)'* (RIBA 2009b, p.3) The DER must not exceed the TER in order to comply with building regulations (Scottish Government 2008c, p.84; Scottish Government 2013a). An alternative way of meeting Standard 6.1 without the use of SAP is to design to the set of values used for the 'notional dwelling' as described in clause 6.1.6. (Scottish Government 2013d). When using the SAP method the DER is calculated at both pre-construction stage (optional) and as-built dwelling at practical completion using the results from the air permeability tests. The result of this final SAP calculation will result in an A to G rating on an Energy Performance Certificate (EPC) which is a requirement of the EPBD (Scottish Executive 2012e, p.p33; European Parliament 2010). The approach required by the legislation encourages the use of low carbon technologies (LCT) and their use is mandatory in future certification levels, and the "Active" versions of the Section 7 Standards (Scottish Government 2013d). Scotland and the rest of the UK use this carbon emission calculated using the SAP methodology rather than of a target stating the maximum level for total space heating or electrical energy use figure used in legislation and ultra-low energy concepts (Passivhaus) across Europe.

4.2.4.3. Section 7, Building Standards- Domestic, Sustainability Definition

Introduced in 2011, Section 6 of the Scottish Building regulations defines Sustainability levels, or bands which are based on compliance with a series of checklist criteria. As a starting point the meaning of 'sustainable development' adopted by the Building Standards is the 1987 Brundtland Commission of the United Nations version: *"the needs of the present without compromising the ability of future generations to meet their own needs"* (United Nations 1987). As stated in the *Technical Handbook*, to meet the requirements of this meaning of sustainability the built environment should account for (Scottish Executive 2013h, p.417):

- social, economic and environmental factors
- the potential for long-term maintenance of human well-being in and around buildings
- the well-being of the natural world and the responsible use of natural resources,
- without destroying the ecological balance of the area where these resources originate or are processed and

- the ability for the built environment to be maintained

The stance used by the Building Standards is that by “*defining higher standards to measure sustainability will enable higher quality buildings to be created and for such benefits to be formally recognised*” (Scottish Executive 2013h, p.417). The assessment of sustainability is certified through the Section 7 of the Building (Scotland) Act 2003 and can also be applied for retrospectively. The Section 7 methodology is the only recognised assessment methodology for regulatory sustainability in Scotland. Section 7 covers two very broad issues; ‘Climate change, energy and resource use’ and ‘*Quality of life; material use and waste*’ which were deemed unsuitable to integrate into the original 6 sections of the standards due to their complexity. A number of checklist aspects are defined to determine the sustainability levels. The Section 7 appears to be based loosely on the tick box criteria of the much criticised *Code for Sustainable Homes* (CSH) methodology, the sustainability assessment method used in England and Wales. Similarly, the section encourages the use of renewable energy technologies rather than significant reduction of heating energy requirements. Both Section 7 and CSH focus on carbon reduction compared to previous regulations, checklists and relatively generous performance requirements rather than defining strict energy targets and fabric efficiency standards.

Section 7 is divided into eight different sustainability aspects (Scottish Executive 2013h);

- 1: Carbon dioxide emissions
- 2: Energy for space heating
- 3: Energy for water heating
- 4: Water use efficiency
- 5: Optimising Performance
- 6: Flexibility and Adaptability
- 7: Well-being and Security
- 8: Material use and waste

Carbon Dioxide Emissions Aspect

The Scottish net zero carbon definition does not base its initial standpoint from an existing sustainability assessment standard such as the CSH and Ecohomes, however, the building standards sets a framework for sustainability assessment for housing in the Sustainability section. There are six sustainability levels, the first five are fully defined and Bronze is mandatory (achieved with compliance of Sections 1-6) with associated carbon reduction criteria;

Bronze- 2010 Building Regulations (30% less than 2007)

Bronze Active- Current Building Regulations with LZCT (30% less than 2007)

Sliver 45% less than 2007 (21.4% lower than 2010 TER)

Sliver Active- 45% less than 2007 with LZCT

Gold 60% Less than 2007 (42.8% lower than 2010 TER)

Platinum 100% Less than 2007 (Zero Carbon)

These levels are similar to the carbon reduction targets suggested by the LCBSSS implying (in terms of carbon reduction) that the equivalent to the gold standard should be implemented in 2013;

2010- 30% Carbon saving over 2007 standards

2013- 60% Carbon saving over 2007 standards

2016/17- 100% Carbon saving over 2007 standards (net Zero Carbon)

2030- Ambition of Total Life Zero Carbon Buildings

Energy For Space Heating Aspect

The current Section 7 defines heating energy requirements for the Silver and Gold standards:

Silver; 40 kWh/(m²a) for houses & 30 kWh/(m²a) for flats.

Gold; 30 kWh/(m²a) for houses & 20 kWh/(m²a) for flats.

These figures offer a decrease in comparison to the FEES standards defined by the Zero Carbon Hub; 46 kWh/(m²a) for houses & 39 kWh/(m²a) for flats. However, these figures are much higher than the Passivhaus ultra-low energy concept (Zero Carbon Hub 2012; Scottish Executive 2013h, pp.423, 427). The approach taken for different targets for different housing forms is to allow for the backstop u-values and therefore wall specifications to be similar between less efficient typologies (detached houses) and more efficient typologies (flats), a stance also taken by the Zero Carbon Hub's definition of a minimum fabric efficiency standard. The Scottish standards do not yet define an fabric approach to meet the Silver, Gold or Platinum standards. The specific approaches and backstop values to achieve these figures may be implemented within Section 6 in future revisions if the standards follow a similar methodology to previous revisions and the FEES standards.

Energy For Water Heating Aspect

This section covers Domestic Hot Water (DHW) defined with Silver requiring 5% from renewables and Gold 50% from renewable sources. It ensures that to meet these standards, the dwelling must be fitted with one or more of the following technologies; solar thermal water heating and associated storage or heat recovery from grey water.

Other Aspects

Section 7 also covers other aspects that are not specifically related energy use such as; provision for extra storage and working/office spaces, improved day lighting, security systems, water saving features, quick start home guides and greater noise separation. Sustainability Labels are also mandatory, implemented as part of Section 7 (similarly to SAP ratings) are aimed to add value to sustainability and are a direct result of the EPBD (Scottish Executive 2012e, p.45).

Cost Implications

The report: '*Cost Impact of Sustainability Labelling for Domestic Buildings*' published in 2011 estimates the increase in costs from Bronze to Silver and Gold (Scottish Executive 2011a). The study uses an average of six common housing prototypes, three social housing and three private sector types (Scottish Executive 2011a,

p.15). The increase from Bronze (2010 Standards) to Silver (21.4% less CO₂ emissions) as £9,393, 11.21% and in increase from Bronze to Gold (42.8% less CO₂ emissions) as £23,025, 27.72% (Scottish Executive 2011a, p.8,9). The aspects that cost the most between Bronze and Gold improvements, in order of cost are; Energy for water heating, Well-being and security, Carbon Dioxide Emissions and Energy for space heating.

4.2.4.4. Scottish Development of Future Standards

The most recent 2013 Building Standards introduction for Section 6 mentions the recommendation for the staged improvements in energy standards in 2013. The 2013 improvement should see all new housing to reach '*very low carbon building*' status with a 60% carbon saving over 2007 standards (proposed in the Sullivan Report) but does not implement them within the new standards. However, in September 2013 in response to the consultation in January 2013 the Government announced that from October 2015 a 21% carbon reduction target (compared to current levels, 45% compared to 2007) would be implemented for new build domestic dwellings with a much higher target for non-domestic dwellings (around 43% average). This improvement in domestic dwellings was called for by 2013 in the LCBSSS (Scottish Government 2013b). Part of the reason for the change in target dates is that major house builders lobbied the government through Homes for Scotland requesting a postponement to legislation (Murray & Millar 2013). The argument is based on the financial crisis and the increased costs through carbon emission savings would push house prices up, therefore making houses more difficult to finance through savings or mortgages. To achieve this target, there will be a higher airtightness value, improved fabric performance, improved heating controls, higher efficiency heating systems and some building types, greater use of low carbon technologies (Scottish Executive 2013c, p.123; Scottish Government 2012a). The Energy and Sustainability Section 7 remain almost unchanged from the previous 2011 edition of the Building Standards with no increase in performance required (Scottish Government 2013d). Due to the new implementation of carbon reduction emissions in 2015, it seem highly unlikely that the recommendation of Zero Carbon homes by 2016/17 made by the LCBSSS will be achievable in such a short timescale, this point is discussed in the methodology section (5.2.2).

4.2.5. EPBD and Zero Carbon Homes

EPBD 'nearly zero energy' definition and use in the UK

The European *Energy Performance Directive for Buildings* legislation (EPBD) has directly generated the development of legislation for Zero Carbon Homes in the UK, such as the CSH and the Scottish Section 7. These approaches define some of the strictest performance targets throughout the world, however, the wording in the EPBD allow for some alternative interpretation of its requirements. Within the EPBD definition of nearly zero energy is only defined as '*nearly zero energy building*' means a building that has a very high energy performance' (with a calculation methodology framework in Annex 1) with the required energy being '*covered to a very significant extent by energy from renewable sources*' (European Parliament 2003, p.18). This wording and definition allows the member state to propose a reasonable, detailed definition for 'nearly zero energy' (NZE).

EPBD ‘nearly zero energy’ Definition and Local Climates

The original EPBD specifically states that the local climate should influence the minimum energy performance requirements (European Parliament 2003). It also states that in respect to local climates *“Best practice should ... be geared to the optimum use of factors relevant to enhancing energy performance”* (European Parliament 2003, p.2). However, it defines the methodology used for calculating energy performance to be applied at a *“national or regional level”* (European Parliament 2003, p.3).

The EPBD 2010 re-cast document suggests an updated definition of the calculation methodology of energy performance that differs slightly from the original document. It states that the calculation of the energy performance should *“be calculated on the basis of a methodology, which may be differentiated at national and regional level”* (European Parliament 2010). This unclear level of accuracy in geographic area could be interpreted as a requirement for NZEB to respond to the local micro climates found across nations or at a national level.

The UK and Scottish Government’s chosen building performance simulation methodology (SAP) uses average climate data and therefore does not support any regional climate data (BRE 2011a). In some geographically smaller nations that have little change in climate utilising this method would have little effect on results. However, in the UK the variation in climate between its north and south extremities will have a marked effect on space heating energy use estimates and this is used as the basis for the research outlined later in this thesis.

Scotland ZCH Target

In Scotland there are now major issues for the government and stakeholders in the construction industry if they intend to reach ZCH by 2016 due to late implementation of the recommendations from the Sullivan report. The recommended carbon reduction target of 45% to be implemented in the 2013 revision of Section 6 is now proposed to be implemented sometime in 2015, leaving very little time for the building industry to reach the Zero Carbon Status (Scottish Government 2013b). As a result of this it would appear that Scotland is now proposing the requirement for ZCH to come into force by 2021 rather than 2016/17 inferring that this is Scotland’s definition of NZE (Scottish Executive 2013a, p.8). It is unclear if the Scottish definition of ZCH or NZE will take cues from the Zero Carbon Hub research. The proposal of Allowable Solutions is mentioned in the most recent update of the Sullivan Report’s progress but its position is unclear (Scottish Executive 2013a).

NZEB though ZCH- Costs Increases and Preferred Approach

The latest EPBD recast has been developed from the *Action Plan for Energy Efficiency* which states that there is *“significant potential for cost-effective energy savings in the buildings sector”* (Commission of the European Communities 2006). This highlights the need for cost effective solutions when developing NZEB. It could be argued to provide the most ‘cost effective’ NZEB is a fabric first approach that sets a high standard for

minimum fabric performance as the predominantly fabric first Passivhaus concept can be built with little or

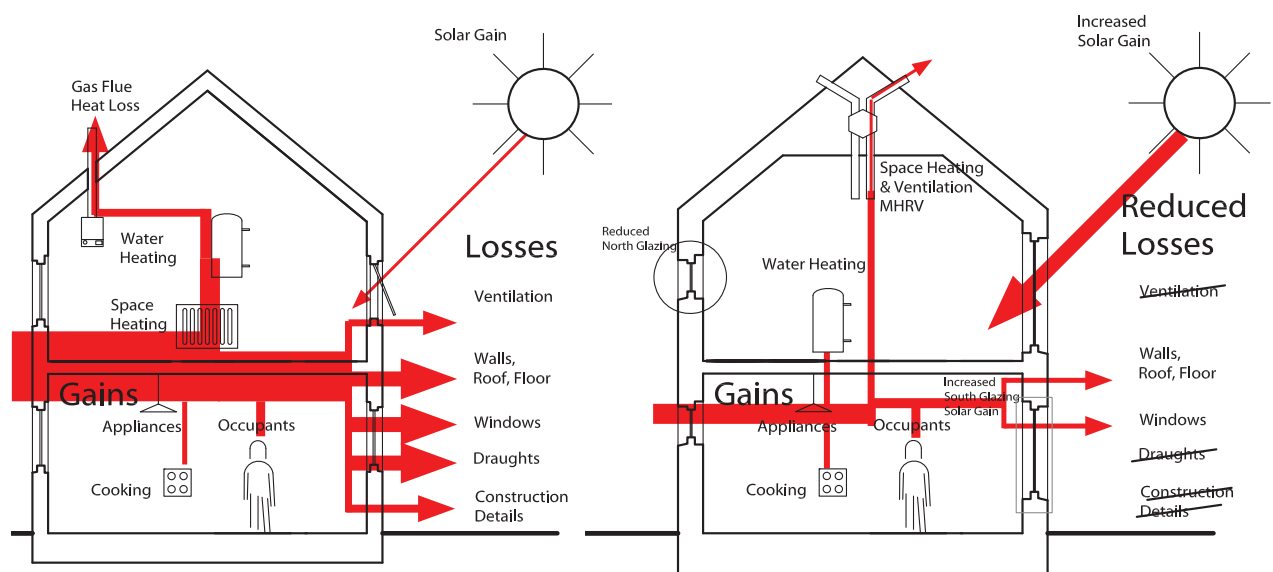


Figure 52- Standard House vs Passivhaus Sources of Heat Gains & Losses

no increase in construction cost in some European countries (Bere 2013). However, the ZCH interpretation of close to Passivhaus building fabric is proven to be more expensive than a system that has reliance on a PV array in a recent Zero Carbon Hub report (discussed further in 5.2.3) (Zero Carbon Hub 2014c, p.7).

4.2.6. Passivhaus Ultra-Low Energy Concept

[Figure 52]

Passivhaus is an ultra-low energy concept that aims to achieve a high level of thermal comfort with the least energy use. It employs a fabric first approach for ultra-low energy construction; it focuses on reducing energy demand rather than integrating renewable technologies. It uses a super insulated envelope, MVHR and employs a mandatory high level of airtightness to achieve very low specific space heat demand of 15 kWh/(m²a)(Mead & Brylewski 2012). In order to reliably achieve this target, the concept employs a sophisticated thermal simulation program, the Passivhaus planning package (PHPP)(Passivhaus Institut 2007). From 1998 to 2001 the Passivhaus concept and PHPP has been rigorously tested and proven through the CEPHEUS Programme (CEPHEUS 2001). Passivhaus has been applied in housing extensively across the world with over 37,000 examples (as of 2012) of Passivhaus in use and is proven to be cost effective (~+10% premium) and in Europe, this has facilitated the growth of a PH certified construction industry familiar with the more stringent construction techniques required (Cutland 2012; Passipedia 2012a).

4.2.6.1. Passivhaus Description

The Passivhaus is an ULEH concept developed by Swedish Professor Bo Adamson and German physicist

Wolfgang Feist originating from the late 1980's. The key starting principle behind a Passivhaus is based on the concept by Amory Lovins of reducing investment through energy efficient design. The concepts original aim was to *'create an even more energy efficient dwelling that combined the architectural means with the existing technology'* (Müller & Berker 2013, p.588)(Feist 2004). Early calculations revealed that the building's compactness was relevant for energy savings but existing typical components were not of a suitable standard to achieve ultra-low energy housing targets. These initial findings were key in the generation of the standardised set of requirements that make up the current Passivhaus standard. The name comes from comfortable indoor temperature without active heating or cooling, however, in practice, most Passivhaus have a small active heating system but with radically reduced space heat demand. The official definition is *"A Passive House is a building, for which thermal comfort (ISO 7730) can be achieved solely by post-heating or post-cooling of the fresh air mass, which is required to achieve sufficient indoor air quality conditions – without the need for additional recirculation of air* (Passipedia 2013c)".

Passivhaus was launched in 1988 by Wolfgang Feist during a research period at the University of Lund/ Sweden (Passipedia 2013d). The early stages of development of the standard could be said to come from the 1989 Nulli Zero Energy House in Dörpe that involved members of the Passivhaus Research Group. It performed to almost Passivhaus standards, and it's predicted results would have exceeded Passivhaus (Passipedia 2012b). The Passivhaus concept was first fully tested in a terraced house in Darmstadt in 1991 which proved the concept by reducing the heating need by a factor of 10 (Feist 2006; Müller & Berker 2013; Passipedia 2013d). The project allowed for the definition of the Passivhaus standard's requirements and the theoretical proof of the standard published in *'Passive Houses in Central Europe'* (Feist 1993).

Using a fabric first approach to energy conservation, the stringent energy use requirement of 15 kWh/(m²a) was reliant on a very high specification thermal envelope, prototype triple glazed windows with mechanical heat recovery ventilation. This figure was determined to be the most cost effective by a working group on cost efficient passive houses (Passivhaus Trust 2013d; Feist 2013). It resulted in heating demands equivalent to just 10% of a standard house setting the current benchmark performance for affordable ultra-low energy housing in mainland Europe. Passivhaus is not a simply implemented energy standard with static backstop values as found in some European building regulations, it requires an approach to architectural design and a knowledge of technical details. A central tenant to achieving ultra-low energy housing embodied in Passivhaus lies with the use of mechanical ventilation heat recovery systems (MVHR). These air-to-air heat exchangers (often misunderstood for air conditioning systems) have had the most radical and controversial implications on design as they precisely control ventilation air changes. High levels of efficiency can be achieved, as up to 94% of the energy in the exhaust air is transferred to the fresh air intake reducing a major component of current energy loss in standard housing. Passivhaus is not just limited to residential housing, schools, community centres and offices have all been certified to the Passivhaus standard. It is based on optimisation of all energy relevant components: building shell, including windows & doors, ventilation, heating, hot water, auxiliary electricity and household electricity(Intelligent Energy Europe 2011).

Therefore the five basic principles of the Passivhaus standards are: (Müller & Berker 2013; Passipedia 2013a):

- High level thermal insulation,
- Passivhaus windows,

- Ventilation with heat recovery (>75% efficiency),
- Airtightness detailing
- Thermal bridge free design

The Passivhaus defines a series of energy targets, but does not determine a construction method or design (Intelligent Energy Europe 2011). These basic principles achieve the following mandatory targets, proven pre construction by the building energy calculation tool, PHPP (exception of airtightness) (Mead & Brylewski 2012)

- Specific Space Heating Demand: $\leq 15 \text{ kWh}/(\text{m}^2 \text{a})$
- Specific Space Cooling Demand: $\leq 15 \text{ kWh}/(\text{m}^2 \text{a})$
- (or) Specific Heating Load: $\leq 10 \text{ W}/(\text{m}^2)$
- Specific Primary Energy Demand $\leq 120 \text{ kWh}/(\text{m}^2 \text{a})$
- Site tested Airtightness $\leq 0.6 \text{ ach @ } 50 \text{ pascals (n50)}$ (positive and negative pressure)

The Specific Space Heating Demand (SSHD) is the amount of heat energy required to heat 1 m^2 of the building per annum. The heat load is the highest amount of heat (power) required to heat 1 m^2 of the building over a year. The figure $\leq 10 \text{ W}/(\text{m}^2)$ heat load enables the MVHR to heat the house using only air with an electric or hot water post heater, this removes the requirement for a traditional heating system.

Specific Primary Energy Demand covers the energy consumed by DHW, heating, cooling, auxiliary and household electricity.

The airtightness figure is one of the most demanding construction targets, requiring specific detailing at the design stage, and stringent on-site management in order to preserve membranes and taping (Intelligent Energy Europe 2011).

There are also broad fabric specification guidelines to achieve the required target, similar to FEES; low opaque element u-values $< 0.15 \text{ W}/\text{m}^2$ and low glazing u-values $< \sim 0.8 \text{ W}/\text{m}^2$ with a solar heat gain coefficients (g-value) > 0.5 (Passivhaus Trust 2013d; Intelligent Energy Europe 2011).

4.2.6.2. Passivhaus Institute & Certification

Passivhaus is a commercial concept based on the '*fundamental laws of physics*', it was not developed as a standard or part of legislation, in 1996, an independent research institute, the Passivhaus Institute (PHI) was founded by Dr Wolfgang Feist (Passipedia 2013b; Passipedia 2012b). The Passivhaus institute or associates maintain the control over the Passivhaus concept. The creation of the PHI and its certification scheme, a technological niche was created that quickly developed in to a commercial niche (Müller & Berker 2013; Schot & Geels 2008). The certification scheme requires the building to go through certification process (BRE 2011d). The recommended process is to use an accredited Passivhaus Designer/Consultant who will then generate a PHPP calculation. This should integrate standard PHI approved thermal bridge free details, if non-standard details are used extra thermal modelling may have to be performed at the discretion of the certifier to prove the performance of the detail. The specification should use PHI certified Passivhaus components,

if other components are used there is a lower performance figure of any non-certified products (Cutland 2012; Pokorny et al. 2008). The design and PHPP is then checked for full compliance by a Passivhaus Certifier, currently there are three in the UK (BRE, Cocreate Consulting, Warm), this process can cost in excess of £1500 in the UK (Passivhaus Institut 2012a; BRE 2013b). The approved design is then built and pressure tested (in accordance with EN13829) during the first fix (to resolve issues) and at completion to confirm the airtightness level of $\leq 0.6 \text{ ach @ } 50 \text{ pascals (n50)}$ has been achieved. The contractor confirms in writing that the building has been built in accordance with the contract documentation. The house is then issued with a Passivhaus certificate stating that it is a Quality-Approved Passivhaus (Mead & Brylewski 2012).

PHPP

The Passivhaus concept is highly sensitive to small changes in design and specification, this sensitivity is quantified by using a highly detailed building simulation tool, a requirement for design and certification. The Passivhaus Planning Package (PHPP) is an Excel based calculation that is used for modelling Passivhaus designs, it primarily outputs detailed data and calculations regarding space heating demand and primary energy use (Passivhaus Institut 2007). See section [2.6] for further information on PHPP.

CEPHEUS

[Figure 53]

The Passivhaus concept was regulated and tested against the CEPHEUS Post Occupancy monitoring. The CEPHEUS project ran between 1998 and 2001, it involved the construction and scientific evaluation of 221 housing units built to Passive House standards in five European countries (Passivhaus Institut 1997; CEPHEUS 2001).. Some of its goals include; demonstrate technical feasibility, cost effectiveness across Europe, user behaviour and to present the Passivhaus concept to the world through EXPO 2000 (CEPHEUS 2001).

An important result of the CEPHEUS research project was to correct errors between simulated and actual figures generated by PHPP. As a result alterations are made based on research to improve accuracy of PHPP since the first version in 1998 (Passivhaus Institut 2012).

Passivhaus Cost Implications

The CEPHEUS project revealed the cost increases from 0-17% above typical new build costs. The project revealed average additional cost across the whole of continental Europe was 8%, and in Germany was 10% (Cutland 2012; CEPHEUS 2001). The Passivhaus Institut estimated that in 2012 a residential Passivhaus in

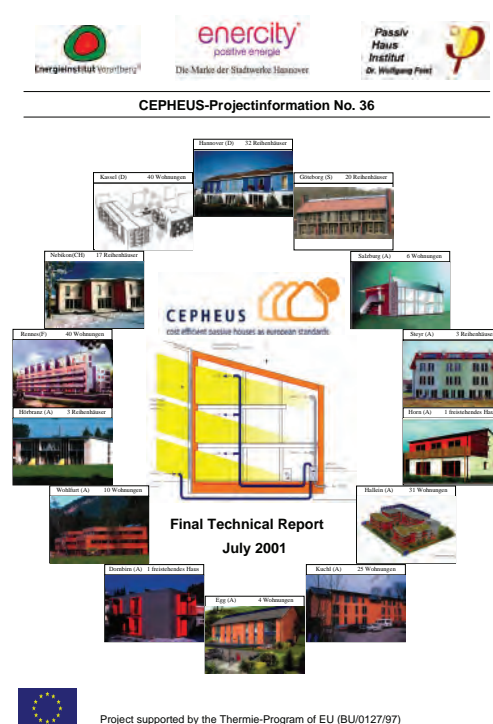


Figure 53 CEPHEUS Report (CEPHEUS 2001)

Germany now costs between 3 to 8% more than building to EnEV (German Building Standards); this cost is higher in countries where Passivhaus is less well established (Cutland 2012; Hines 2012). It has been proven that in some cases Passivhaus buildings can be built at no extra cost in the UK (Hines 2012, pp.253–258; Bere 2013). A recent whole life costing of PH in the UK revealed in most cases using the concept over 30 years it should have a lower whole life cost than a typical new build house due to reduced energy costs (Brown & Price 2014).

4.2.6.3. Passivhaus in the UK

From the certification of the first Passivhaus in 2009, the uptake in Passivhaus in the UK has been accelerating, with approximately two hundred certified built examples and more under construction (Passivhaus Trust 2013d). The examples are not limited to residential units in accessible areas as there

is a Passivhaus community centre in Gairloch, north west Scotland (Neil Sutherland Architects 2013). There are six Passivhaus certified developments in Scotland, these are; Tygh-Na-Cladach [Figure 54]& Midmar by Deveci (2009), Plummerswood by Gaia Architects (2011), Craigrothie House [Figure 55] by Locate Architects (2011), Dormont Estate by David Major (2011) and the Farmhouse by Kirsty Maguire (2013) (Passipedia 2012a; Passivhaus Trust 2013c; Passivhaus Trust 2013a; Maguire 2013). Cost implications for developing Passivhaus in the UK can be high due to the under skilled construction industry and the requirement for higher performing building components imported from mainland Europe. More products certified from Passivhaus are being produced in the UK, such as the Vale Window and the Beattie Passive Build System but, numbers are still limited (BERE Architects 2011). The Beattie Passive Build System was the first UK company to be awarded certification by the Passivhaus Institut as a '*Passivhaus continually insulated building system*' (Passivhaus Trust 2012).

Passivhaus Research

The UK climate differs (in some cases significantly) from that of mainland Europe, which is the leading source of published ultra-low energy building research (Passivhaus- Germany\Austria, Minergie- Switzerland) in temperate climates. Therefore research and products from mainland Europe are not always suitable



Figure 54-Gökay Deveci, Dunoon, Tygh-Na-Cladach



Figure 55- Locate Architects, Dairsy, Craigrothie House

in the UK and Scotland. To date BERE Architects have generated much of the published innovative research into low cost UK Passivhaus, having designed the Lime House (2009) [Figure 56] Larch House (2009) [Figure 57] and Ranulf Road (2010). The Lime house is one of the first affordable approaches to Passivhaus in the UK employing locally sourced materials (BERE Architects 2012b). The Larch House (2009), illustrates that Passivhaus can be used in conjunction with CSH using the Passivhaus fabric performance concept and methodology with the Integration of low carbon energy generation technologies to create an ultra-low energy, low cost, CSH Level 6 compliant house (BERE Architects 2012a). The book *An Introduction to Passive House* by Justin Bere encapsulates much of their research including cost and interior quality in addition to a series of case studies (Bere 2013). A significant amount of research into Zero Carbon homes and some into Passivhaus has been performed in England. However, the climate in many parts of Scotland can differ significantly from the rest of the United Kingdom, this means that approaches for ultra-low energy housing developed for England, Ireland and Wales will require adaptation for use in Scotland. Mark Siddall worked on one of the largest Passivhaus developments in the UK and has produced numerous research papers exploring technical issues regarding heat loss and occupant satisfaction (Siddall 2013). There is limited published research on Passivhaus in Scotland the majority focuses on a few key areas, for example; Bell has investigated suitability of PH in the UK climate, climate change and Scottish climate data (Bell 2011); Porteous has investigated supply chain and costs of



Figure 56- BERE Architects, Ebbw Vale, Lime House



Figure 57- BERE Architects, Ebbw Vale, Larch House



Figure 58- GAIA Architects, Innerleithen, Plummerwood

achieving PH in the UK (Porteous & Menon 2008), Tuohy & Butler have carried out post occupancy evaluation studies of Scottish Passivhaus (Tuohy et al. 2012; Butler & ARUP 2013); Tuohy also compared PHPP to building simulation methodologies (Tuohy & Langdon 2009). There is no research or specific guidance regarding general strategies for designing ultra-low energy buildings in Scotland. Within Scotland there is some published research on sustainable building design and research projects. Guides have been published looking at sustainable design such as '*Design of Sustainable Rural Housing*' and '*Sustainable Housing Design Guide*' but they do not focus specifically on achieving ultra-low energy performance (John Gilbert Architects et al. 2006; Stevenson 2000). Scottish guidance is discussed more in section 4.4.

Post Occupancy of PH in Scotland

Research studies have and continue to produce important findings based on post occupancy monitoring analysis. In 2011 a post occupancy monitoring study was performed on the 2011 Dunoon Passivhaus, it analysed many factors of the building. These include; temperatures CO₂ levels, solar radiation and system performance (Tuohy 2011; Tuohy et al. 2012). The research outputs of this study include improvements to the initial built house, a critique on the Passivhaus certification process and a study investigating performance of Passivhaus in Scottish summer months which highlighted the need to take into account the users level of comfort or discomfort (Lamond 2011). There is a currently an ARUP monitoring study on a the Plummerswood Passivhaus in Innerleithen by Gaia architects(Gaia Group 2013)[Figure 58]. This study will determine occupant behaviour and comfort in a Scottish context focusing on the use of the requirement and use of the MVHR system (GAIA Architects & Passivhaus Trust 2013; Butler & ARUP 2013). The study is also determining the effects the user behaviour and technical system on the energy consumption in order to make the building more energy efficient. Current results illustrate a lower energy consumption than a Level 6 CSH house (Passivhaus Trust 2013c).

Further information regarding the use of PH in Scotland can be found in the methodology section.

4.2.7. Critical Analysis of ZCH,S7 & PH

This section discusses and critiques approaches, uptake, design guidance and units employed in Zero Carbon Homes (including Section 7) and Passivhaus.

4.2.7.1. Comparison of Zero Carbon Homes and Passivhaus

Comparison of Approaches

[Figure 59] Comparison Table

The two most rigorous technical approaches to low energy housing in Europe are embodied in the UK's ZCH (formally Code for Sustainable Homes Level 6 Carbon Saving Section) and the Passivhaus concept. Scotland shares a similar aim with a similar definition of ZCH outlined in *The Sullivan Report* (Scottish Government 2007a). However, their methodologies and use differ. The Scottish ZCH legislation is manifested in Section 7, Sustainability Section of the Scottish Building Regulations (Scottish Government 2012e). As the Scottish regulations appear to be partly referencing the Zero Carbon Hub's research and the lead taken by the English

Section 7- Scotland, ZCH and Passivhaus Energy, Assessment and Fabric Comparison

	ZCH England\ Wales	Section 7, Gold Standard Scotland	Passivhaus
Carbon Dioxide Emissions	0 kgCO ₂ /m ² /a OR 10-11kgCO ₂ /m ² /a +	60% Lower than 2007 42.8% Lower than 2010	Not Specified
SSHD Maximum	46 kWh/(m ² a)- Semi\ Detached* 39 kWh/(m ² a)- Mid Terrace*	30 kWh/(m ² a)	15 kWh/(m ² a)
Airtightness	10 m ³ /h.m ² @50Pa ** 3***-6 m ³ /h.m ² @50Pa*	7 m ³ .h1.m ² @ 50 Pa	1 m ³ .h1.m ² @ 50 Pa ≤ 0.6 ac/h @ 50 Pa
Renewable DHW	Not Specified	50% of Requirement	Not Specified
Ventilation	Not Specified If airtightness <6 m ³ /h.m ² @50P Defined strategy is advised	No requirement >70%MVHR if used	Mandatory >75% MVHR
Assesment Method	SAP 2009/12 UK Average Climate Data	SAP 2009 UK Average Climate Data	PHPP Regional Climate Data

+ Allowable Solutions

*ZCH Suggested **2010 Regulations ***with MVHR

Figure 59- Technical Comparison of Passivhaus, ZCH and Section 7 (Gold)

definition the majority of the following section does not differentiate between the two.

The original UK definition of ZCH was the highest mandatory aspirational code for sustainable housing, however, the definition has changed a number of times since its 2006 debut as described in section 4.2.3.1. The ZCH definition is clearly responding to the EU requirement for a strategy to produce ‘*nearly zero energy buildings*’ (NZEB) by 2020 (Scottish Executive 2013a). The current UK standards do not primarily focus on achieving ultra-low space heating and do not require thermal performance levels near Passivhaus, but they provide sustainability sections for compliance. ZCH provides the ability to mitigate the increased SSHD by generating low-carbon energy from renewable technologies or through ‘*Allowable Solutions*’ carbon offsetting (Zero Carbon Hub 2014e).

Passivhaus is not currently legislation but it has set arguably the most stringent energy efficiency requirements worldwide. The concept and criteria has changed little since the 1st Passivhaus in 1991 apart from some incremental changes to the building simulation methodology (PHPP) based on post occupancy evaluation research.. Although developed before the requirement for NZEB it can still be employed as an approach to achieve an ultra-low space heating.

Scale of Adoption

There are currently over 37,000 Passivhaus certified examples (as of 2012) worldwide, proven across many varied climates (Passipedia 2012a). There were around 250 Passivhaus buildings completed and certified in the UK by the end of 2013 (Passivhaus Trust 2014). In contrast, as of March 2012, there are only 142 (CSH L6) Zero Carbon Homes (ZCH) (Department for Communities and Local Government 2012). As the Scottish Government has yet to define the criteria for the anticipated Platinum Standard of the Scottish regulations, the highest regulatory standard of sustainability, there are currently no built examples to compare (Scottish

Government 2012b). While the built numbers of private and commercial sector CSH and ZCH compliant houses are growing slowly, the majority are expensive research prototypes.

Design Guidance

Information from the Zero Carbon Hub and the Scottish Government detail technical targets and examples of technical solutions to problems rather than suggesting fundamental approaches to low energy design. For example, guidance on best practice for designers and developers such as optimal site orientation for higher solar gain and more compact housing forms with related implications. The Passivhaus course and concept attempts to provide design advice from the outset to make efficient use of solar gains and minimise losses as part of the basic approach (Passivhaus Institut 2007).

ZCH Fabric comparison with Passivhaus Fabric Specification

Despite the ambitious aims for the original Zero Carbon targets, current legislations recommendations of a minimum fabric efficiency for Zero Carbon homes is well below other European ultra-low energy approaches such as Passivhaus (Zero Carbon Hub 2009). This approach reinforced by the '*Defining A Fabric Energy Efficiency Standard*' (FEES) report which defines a maximum space heat demand figure of 39 and 46 kWh/m²/a dependant on housing typology to ensure similar wall specification. However, if the main aim is to build the most efficient ZCH, could the build-ups not alter with dwelling type to offer the most efficient solution? Furthermore, if ZCHs are designed primarily to utilise the most energy efficient fabric to reduce demand for energy, it would allow for reduction in the need for low and zero carbon active technologies or carbon offsetting. Passivhaus uses a fabric first approach which enforces a SSHD of 15 kWh/m²/a for all building types that requires tailored wall build-ups per building.

For comparison a ZCH FEES translates to a wall u-value of 0.15 W/m²K and a roof value of 0.13 W/m²K for a detached FEES dwelling. A typical UK PH dwelling has a wall u-value of 0.113 W/m²K and a roof u-value of 0.096 W/m²K (PassNet 2010b; Zero Carbon Hub 2014c).

Comparison of Passivhaus & ZCH\57 Units

The UK's ZCH uses units of carbon emissions (CO₂ kg/m²yr) in order to relate to the legislations focus on carbon saving, however, this is the only nation to do so (Economidou 2011). The carbon emission unit is complex due to energy generation carbon weighting. Almost every other nation uses units of energy (kWh/(m²a)) or an EPC score (*ibid*). The UK's ZCH also uses alternative units for airtightness (m³/m²h), which requires calculations for each building to compare to the Passivhaus' 0.6 ach@50Pa universal target. The difference in calculation methodologies makes it very difficult for comparative analysis between nations (Jensen et al. 2009; Economidou 2011). Passivhaus uses an energy demand methodology measured predominantly in kWh/(m²a), rather than carbon saving targets. This allows for better comparisons between buildings directly relating to thermal gains and losses. The Passivhaus concept predominantly focuses on the SSHD which can

be used as a benchmark to compare with PH buildings or other regulatory standards assuming a constant fabric specification allowing the architectural design variables to be studied rather than the technological specification being the focus. The use of (kWh/(m²a)) avoids the complex calculations to determine the different carbon intensities of fuels and changes in CO₂ emissions over time as the electricity generation mix alters (Cutland 2012; Zero Carbon Hub 2010a).

4.2.7.2. ZCH Critical Analysis

ZCH Allowable Solutions

Unlike Passivhaus which only concentrates on ultra-low energy use, ZCH aims to account for all regulated energy use, through low carbon technologies or through off-site carbon offsetting (Zero Carbon Hub 2014a). The degree of flexibility in creating a ZCH has significantly increased since its introduction, particularly with the introduction of '*Allowable Solutions*' carbon offsetting. However, one of the possible significant issues with *Allowable Solutions*, particularly with the investment to a carbon abatement fund is the end-user may not receive the energy saving benefits due to the fund financing a carbon saving project elsewhere (pending full definition) (Zero Carbon Hub & Marjewycz 2011; Zero Carbon Hub 2014a). Additionally Kibert & Fard state that the UK's ZCH policy weakens the minimum efficiency standard with carbon offsets and the focus must be on building energy performance (Kibert & Fard 2012, p.634).

ZCH Fabric First- Research Findings

The current documentation for ZCH from the Zero Carbon Hub suggests a possible fabric first approach with a near to Passivhaus fabric performance level (Zero Carbon Hub 2013c). However, the Zero Carbon Hubs '*Cost Analysis: Meeting the Zero Carbon Standard*' document states that their interpretation of a near to Passivhaus standard fabric efficiency level is a "*more expensive option in terms of capital costs*" (Zero Carbon Hub 2014c, p.7). The current cost effective approach uses the FEES requirements which fall well short of the leading fabric first approaches of Minergie and Passivhaus relying on a PV energy generation system (Passipedia 2013c; Zero Carbon Hub 2014c). This cost efficient ZCH approach also relies on a component of payment into a carbon saving fund (Allowable Solutions) in order to offset increased energy use (Zero Carbon Hub 2014c). The methodology and exact approach taken in the research regarding the near to Passivhaus prototype specification is unclear. The analysis methodology uses SAP, rather than PHPP. The fabric specification only uses the minimum Passivhaus specification rather than a calculated figure as required for Passivhaus certification. This could increase the heat demand to well above Passivhaus criteria dependant on the efficiency of the building design. The airtightness is defined as 1m³/hr/m² which works

out as 0.25 ac/h@50pa rather than the PH 0.6 ac/h@50pa. It is unclear if extra costing was factored in for this over increase in specification. The inclusion of unnecessary systems such as a standard heating system also appears to have been budgeted for. This would not be required if the type was designed to meet the Passivhaus standard (*ibid*). These issues could undermine the findings of the report, therefore this does not necessarily disprove the use of the Passivhaus concept if implemented properly. The results of the study are questionable, particularly when it was been proven across the world as cost effective.

4.2.7.3. PH Critical Analysis

Barriers for Passivhaus Adoption in the UK

In the UK and Scotland there is a strong following for Passivhaus with organisations such as the Passivhaus trust organising events and research presentations. The Passivhaus course has been running in the University of Strathclyde, Glasgow since 2009. As of April 2014 there are around 69 certified Passivhaus designers in Scotland (Passivhaus Institut 2014). Therefore enthusiasm and knowledge for Passivhaus in Scotland is not an issue. However, there are a number of areas which may present barriers for the widespread adoption of Passivhaus in Scotland.

Air Quality

The Passivhaus approach initially raised concerns over; air quality, lifestyle changes, costs and lack of a skills base in Scotland. These issues were highlighted as factors against its adoption in the new Scottish Building Regulations in the Sullivan report (Scottish Government 2010a). The claims that a reliance on a 'sealed' envelope and poorly maintained or installed mechanical systems, along with the misconception that Passivhaus buildings do not have opening windows, leaves occupants vulnerable to chemical emissions from the materials used in the construction and the potential for increased incidences of diseases such as asthma. However, since the report, Passivhaus projects have been built and proven to be successful in Scotland. Many of the other concerns over air quality have been researched and disproven provided MVHR units are properly designed and maintained (Hens 2012). Despite being called passive, Passivhaus uses an active MVHR unit. Stakeholders such as Dunster critique the Passivhaus approach as: *"not so clever to insist on expensive levels of air-tightness in the temperate south. But is even stranger to demand electricity hungry, fan-driven, heat-ventilation when passive techniques work fine"* (Herring & Dunster 2010; Lowenstein 2011, p.3). However, the Passivhaus approach still emerges as one of the leading ultra-low energy concept in Europe that requires a MVHR unit when combined with the high airtightness requirement to provide good air quality. Conversely, concerns have recently been raised pointing to the potential indoor air quality issues that are predicted to occur in UK zero carbon homes and the higher space heat demands due to the lack of MVHR. It has been argued that not adopting Passivhaus standard might not only undermine efforts to reduce energy wasted in Zero carbon homes but may create hostility from building occupants due to potentially poor environmental quality concerns (Tofield & French 2012).

Costs

The cost of certification, sourcing of Passivhaus accredited building products and lack of construction skills all present problems for the widespread utilisation of Passivhaus in the UK. It is felt that the lack of construction skills regarding airtightness and thermal bridging can be overcome (Cutland 2012). One option could be to use the science underpinning Passivhaus without using the accredited building materials and certification process like Norway (Müller & Berker 2013, p.592). However, this may not necessarily allow for the same quality assurance that is a key component of the Passivhaus certification argument (Passivhaus Institut 2007). Passivhaus success in some countries such as Germany offer reduced interest rate loans and grants which have supported the development of Passivhaus construction industry (Woodman 2013). Therefore Woodman suggests that for Passivhaus to become more successful *“financing issues need to be resolved before it fulfils that potential” (ibid).*

Post Occupancy Evaluation in Scotland and the Certification Process

Post Occupancy Evaluation of the first Passivhaus in Scotland highlighted a number of issues (Tuohy et al. 2012). For certification the design must pass the PHPP (checked by certifier) and the certifier is aware and acknowledges the building products used (if not using certified components). The certification process only requires a signed declaration to demonstrate that the design was constructed as drawn which can lead to discrepancies. The Passivhaus method is reliant on the *“the knowledge and diligence of the individual Designer, the Certifier, the certification requirements, and the provenance of the products used”* (Tuohy et al. 2012, p.7). A deviation from drawings or a breakdown in communication between these stakeholders can lead to inaccuracies between predicted and as built performance. However, this is the case with any approach. As there are no specific on-site checks throughout the building process, nor are there any post completion tests other than the blower door test which measures the airtightness discrepancies can go unnoticed until the building is inhabited. The post occupancy study found that there were a number of issues with the Dunoon Passivhaus requiring remedial action to make the building perform as intended (Tuohy et al. 2012). However, other Passivhaus projects in the UK are performing as expected, if not better, such as Bere’s Camden Passivhaus and Siddall’s Racecourse (Lowenstein 2011, p.3; Mark 2012; Siddall 2013). An on-going Post Occupancy Evaluation of the Plummerswood Passivhaus has revealed that the house is performing as expected and has allowed the occupants to alter their behaviour and save an additional 30% of energy costs (GAIA Architects & Passivhaus Trust 2013; Butler & ARUP 2013).

4.3. Thermal/Energy Analysis Software

There are numerous types and versions of Energy Analysis Software available. Some are mandatory for building regulations in different countries, others are required for low energy concepts certification. The data entry and calculation methodologies differ significantly. The software that is available can be divided into two main groups based on user input; *Numeric Modelling Software* which requires building metrics to be inputted numerically and *Virtual Environment Modelling* software that requires a three dimensional model for building metric input.

4.3.1. Numeric Modelling Software

Much of the current regulatory analysis software requires numeric input. Two main software packages applicable for the UK are Standard Assessment Procedure (SAP) which is required in legislation and the Passivhaus Planning Package (PHPP) which is required when designing a Passivhaus.

4.3.1.1. Standard Assessment Procedure and Simplified Building Energy Model Methodologies

Introduction

The Standard Assessment Procedure (SAP) energy rating is the Government's preferred domestic energy rating methodology. It provides the basis of assessment against the energy standards in the UK Building Regulations (RIBA 2009b, p.9). A SAP calculation is a mandatory requirement when submitting a building warrant for a new house in the UK. SAP quantifies a dwelling's performance terms of: energy use per unit floor area, a fuel-cost-based energy efficiency rating (the SAP rating) and emissions of CO₂ (Gov.uk 2013). The SAP methodology is compliant with the requirements stated in the EPBD for Zero Energy buildings (European Parliament 2010). It is also the basis of assessments for the production of Energy Performance Certificates (EPCs) a requirement of the EPBD.

Development

SAP was derived from the Building Research Establishment Domestic Energy Model (BREDEM) and it follows the British Adopted European Standard: BS EN ISO 13790:2008: *Energy performance of buildings, Calculation of energy use for space heating and cooling* (British Standards Institution 2008). SAP was first published by the Department of the Environment (DOE) (now DECC, the Department of Energy and Climate Change) and BRE in 1993 (BRE 2009).

SAP Future Edition (2012)

In order to improve estimates of energy requirements the BRE has released information stating that the SAP 2012 will offer the option to use regional climate data for some calculations. However, this edition of SAP has only been fully released in April 2014 (BRE 2014; Gov.uk 2014). The new version of SAP 2012 will include regional climate data but only for the Renewable Heat Incentive for display on Energy Performance Certificates (EPC), the output from solar thermal and solar PV systems and running cost estimates and savings (National Energy Services Ltd 2012). SAP 2012 will retain the principle of keeping the SAP and regulatory outputs independent of region. Additionally, the cooling calculation will also become climate independent (BRE 2014). This means that the FEES specification and carbon emissions determining the level that ZCH should achieve will still be based on the average UK climate (discussed below). The remainder of this thesis makes reference to the SAP 2009 (current at time of writing).

Methodology

The basic methodology is in the form of a worksheet with accompanying tables. The basic calculation methodology can be processed by hand on paper or by an approved computer program that uses the

worksheet methodology using a computer interface, which is now the preferred method due to the complexity of the current SAP. *'The BRE approves SAP software on behalf of DECC, CLG (Communities and Local Government), the Scottish Executive, the Welsh Assembly Government, and the Department of Finance and Personnel in Northern Ireland' with a list published on BRE's website.* (BRE 2009, p.11).

Purpose

SAP's primary purpose is to provide accurate and reliable assessments of dwelling energy performances in order to demonstrate compliance with Building Regulations (Gov.uk 2013). SAP can also be used to assess and compare the energy and environmental performance of dwellings. SAP uses the sizes and specifications of the building to then calculate a Target Emission Rate (TER) and the designed Dwelling Emission Rate (DER) which are measured in carbon emissions. It then calculates the overall energy rating and SAP rating for the dwelling (BRE 2009). SAP requires performance information on all the products and materials used in the construction of a dwelling which contribute to the overall energy performance; there is no SAP rating for them individually. The energy rating procedure applies to the whole dwelling rather than its components. Government relies on industry to provide product performance data in the form that is required by SAP. Where this is not available a conservative view on the performance of products and materials has to be taken. The same method is used if thermal bridging specifications are not stated. SAP is updated on a regular basis to incorporate improved understanding of domestic energy use and reflect changes in the technologies used in dwellings (RIBA 2009b, p.9).

SAP Input Methodologies

There are variations regarding the input of data between the manual method and accredited software method. The variation in user input between the software and the manual method is due to the information held within software.

The principle steps in undertaking a manual SAP calculation are as follows (BRE 2009).

- Determine the overall dwelling dimensions
- Calculate the ventilation rate
- Calculate the heat losses
- Calculate the water heating energy requirements
- Determine the internal gains
- Determine the solar gains
- Determine the mean internal temperature
- Determine the degree days
- Calculate the useful space heating requirement and delivered energy
- Calculate the water heating requirement and delivered energy
- Determine the fuel costs from the delivered energy figures
- Calculate the SAP rating
- Calculate the carbon dioxide emissions (and hence the Dwelling CO₂ Emission Rate and the

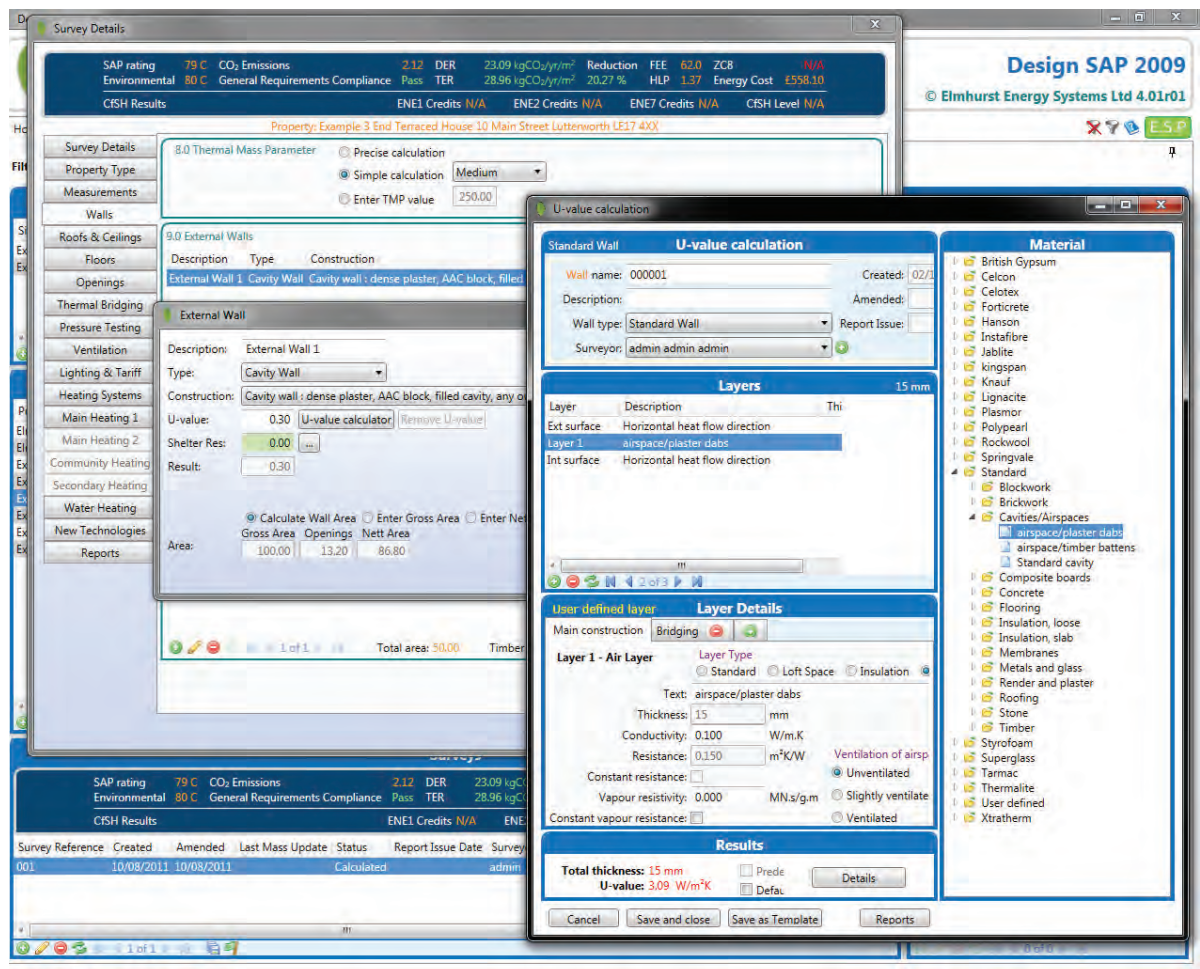


Figure 60- SAP Data Entry Elmhurst SAP 2009

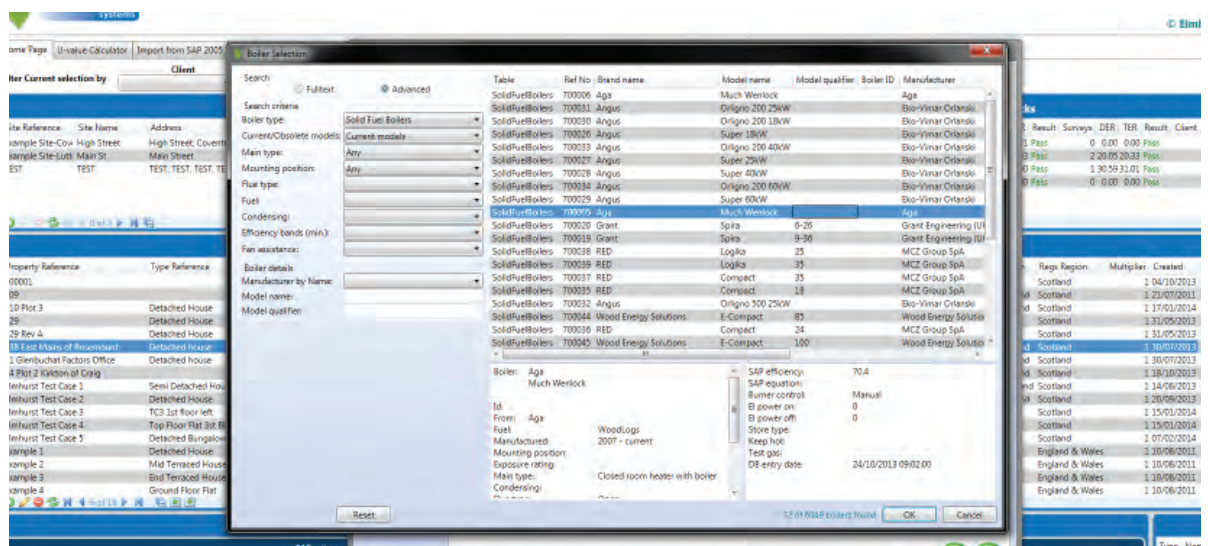


Figure 61- SAP Input Database Elmhurst SAP 2009

SAP Accredited Software

Accredited SAP such as Elmhurst SAP 2009 software offers a step by step wizard that ensures all relevant data has been entered into the program [Figure 60]. Many manufacturers component specifications are available within the software's databases that are periodically updated. [Figure 61] The database allows quick, accurate input of specifications of; technology, systems and materials from manufacturers (Elmhurst Energy Systems 2013). The program will also not allow the user to go forward without completing a section, minimising the chance of missing data leading to errors in the final report. The software also comes with clear manuals and support from the manufacturer.

Data Entry Steps

The principle steps in undertaking a SAP calculation using an accredited software package are as follows: (Elmhurst Energy Systems SAP 2009) (Elmhurst Energy Systems 2013):

- Dwelling location
- Dwelling orientation
- Dwelling typology
- Dwelling measurements
- Walls, roofs, ceilings, floors build-up (u-values)
- Openings
- Thermal bridge specifications
- Pressure test results
- Ventilation specifications
- Energy efficient lighting and electricity tariffs
- Heating systems and specifications
- Domestic hot water heating and specification
- Low and zero carbon generating technology (LZCGT) technology
- Reports page, options to displays; detailed reports, recommendations, SAP rating, DER, TER.

Outputs

The current SAP outputs include the following indicators of energy performance (BRE 2009; Elmhurst Energy Systems 2013):

- Energy consumption per unit floor area (kWh/(m²a))
- Energy cost rating (the SAP rating) 1-100
- Environmental Impact rating (based on CO₂ emissions) 1-100
- Dwelling CO₂ Emission Rate (DER) (kgCO₂ /m²/a)
- Target CO₂ Emission Rate (TER) (kgCO₂ /m²/a)
- Energy Cost (£)

SAP rating

The SAP rating is measured on fuel costs and is the UK's preferred method of energy performance indicator due to the relevance to the householder. *'The SAP rating is based on the energy costs associated with space heating, water heating, ventilation and lighting, less cost savings from energy generation technologies'*(BRE 2009). It is expressed on a scale of 1 -100 with the higher the number the lower the running cost. A figure higher than 100 indicates a net exporter of energy (due to local micro generation) (RIBA 2009b, p.9).. *'SAP energy ratings are independent of location – all dwellings are assumed to be located in the East Midlands. This means that three identical dwellings built in Cornwall, Cheshire and Caithness will all have the same SAP'* (RIBA 2009b, p.9)..

Climate Data

SAP achieves climatic neutrality because it uses a mean average of the UK's weather for the majority of its calculations; space heating, FEE, TER & DER, SAP rating and environmental impact rating (BRE 2011a). SAP uses the following climatic data defined by BRE in its calculations; external temperature, wind speed and solar radiation. The climate data used by the SAP is a mean average of the 21 UK climates which incidentally are the same 21 climates that are offered individually by the BRE for use with PHPP (BRE 2011a, p.104; BRE 2011c). The average calculation does not take into account land mass population. Coincidentally the calculated average climate data exactly matches the East Pennines climatic region (which include the cities Leeds, Hull, Sheffield, Nottingham and Lincoln) which is why some sources state the UK average climate being based in Sheffield (BRE 2011a). The climate data calculates the mean average of the regions irrespective of area or population.

Environmental Impact rating

'The Environmental Impact rating is based on the annual CO₂ emissions associated with space heating, water heating, ventilation and lighting, less the emissions saved by local energy generation systems that are associated with the dwelling.' The Environmental Impact rating is expressed on a scale of 1 to 100: 1 (very inefficient) to 100+ (very efficient). A rating of 100 is achieved at zero net emissions. (BRE 2009, p.7; RIBA 2009b).

Dwelling CO₂ Emission Rate (DER)

The DER is expressed in kgCO₂ /m²/a, it illustrates the annual predicted CO₂ emissions per m² floor area for space heating, water heating, ventilation and lighting, less the emissions saved by local energy generation systems that are associated with the dwelling(BRE 2009). For the building to comply with Building Regulations Part L1A the DER must be lower than the Target Emission Rate (TER) which is generated by SAP dependant on building and fuel type(BRE 2009).

Energy Performance Certificates (EPC)

EPCs are a requirement of the EPBD, the three of the indicators of performance (Energy consumption, SAP rating, and Environmental Impact rating) are used to generate EPCs (BRE 2009; Commission of the European Communities 2008). *'The energy cost (the SAP rating) and the Environmental Impact rating have been mapped on to an A to G label format, similar to that for white goods, in order to improve their visibility and as an aid to understanding'* (BRE 2009, p.7).

SAP Detailed Output

A detailed SAP 2009 report output from accredited software defines the figures used to produce its calculations including; building dimensions, wind speeds, heat loss parameters, internal gains, solar gains, space heating requirements, overheating analysis, technology specifications, CO₂ emissions etc. (Elmhurst Energy Systems 2013). However, this is a series of static tables of information. The calculation of the results is not transparent and any alterations to the input data require the production of a new report.

SAP as a Design Tool

SAP can be used for design, however, the outputs are not as useful during design stage and were intended only as a legislative compliance tool. In order for SAP to be a useful design tool it requires a greater flexibility for new systems to be used, a clearer representation of heating loss and heat gains and a more transparent calculation method. Ideally the development of an effective design should achieve the most efficient building possible with the least technical knowledge whilst allowing for detailed data input.

Performance Gap and Misleading Results

One of outputs the SAP rating determines is cost of energy bills in pounds in order for the householder and prospective buyers to understand and compare different houses with units they are familiar with. This information is displayed on EPCs which are mandatory with the completion of new houses. However, this estimated heating cost and energy performance rating will rarely translate into the actual heating cost due to the variation of the predicted and as built performance of the building. This can be attributed to many causes as documented in various reports (Zero Carbon Hub 2010a; Tuohy & Langdon 2009). However, the SAP rating's predicted heating costs will rarely be possible in Scotland even with the model end-user due to limitations with the base data entered. The lack of accuracy of SAP has been highlighted as an issue in new research from the Zero Carbon Hub, Closing The Gap Between Design & As-Built Performance Evidence Review Report however, this report covers many issues regarding detailed inputs rather than the issues above (Zero Carbon Hub 2014c).

Summary

SAP acts as the UK's low carbon domestic energy calculation assessment software. It does not consider regional climatic variation using average UK climate data for space heating calculations irrespective of the buildings location in the UK. It is primarily a compliance tool, not specifically designed for low energy housing, and not developed as a design tool (Gov.uk 2013). Some versions of the accredited software has access to a database that is periodically updated with UK products for simple input into SAP (Elmhurst Energy Systems 2013).

4.3.1.2. Passivhaus Planning Package Methodology (PHPP) .

Introduction to PHPP

The Passivhaus Planning Package (PHPP) is a Microsoft Excel based, dynamic simulation, building energy calculation tool with inputs and output across 30 worksheets, based around the same core energy calculation standard (ISO 6946) used throughout Europe (including SAP)(Passivhaus Institut 2007). The PHPP is a mandatory part of the Passivhaus certification process.

Calculation Accuracy

The Passivhaus Institute state that the 'behaviour of buildings can be predicted very accurately using a simulation that is based on the fundamental laws of physics' (Passipedia 2013b; Müller & Berker 2013). As stated previously, regular revisions include new research results in its calculation procedures , such as the results of monitored Passivhaus dwellings within the CEPHEUS project for improved accuracy compared with as build designs (Mead & Brylewski 2012; Passivhaus Institut 2007, p.50) (Müller & Berker 2013; Mlecnik et al. 2010). Müller & Berker promote the PHPP as scientifically superior due to the scientific development and continued improvements based on actual monitoring (Müller & Berker 2013). The input data required for dynamic simulation programmes such as PHPP is very comprehensive. If the simulation is to provide reliable results, the data must be correctly determined based on the actual geometry and specification of the building (Passipedia 2013b; Müller & Berker 2013).

Inputs & Calculation Methodology

[Figure 62]

A typical housing model requires over 2,000 independent data entries across a range of 30 sheets (without the climate data set) to be entered in to the PHPP Excel file (Passipedia 2013b). This includes detailed information about heating and ventilation systems, wall build-ups including; u-values and thermal bridging, electrical use in the home and detailed site/conditions (Passivhaus Institut 2007; Passipedia 2013b). Calculations cross reference data from within a single Excel file and require no external links or internet access, additional information such as wall build-ups or climate data are entered through custom data input cells. PHPP was developed specifically as a flexible design and certification tool for ultra-low energy buildings rather than a specific legislative compliance tool such as SAP. It allows for input of customised detailed data input such as regional climate data and specific building elements. Other worksheets can be inserted into

Building: **4 Bed 2 Story** Heat Demand: **11** kWh/(m²a)

Summary						Building Element Overview	Average U-Value [W/(m²K)]
Group Nr.	Area Group	Temp Zone	Area	Unit	Comments		
1	Treated Floor Area		107.00	m²	Living area or useful area within the thermal envelope		
2	North Windows	A	3.80	m²	Results are from the Windows worksheet.	North Windows	0.851
3	East Windows	A	0.00	m²		East Windows	
4	South Windows	A	30.40	m²		South Windows	0.823
5	West Windows	A	0.00	m²		West Windows	
6	Horizontal Windows	A	0.00	m²		Horizontal Windows	
7	Exterior Door	A	2.48	m²	Please subtract area of door from respective building element	Exterior Door	0.810
8	Exterior Wall - Ambient	A	174.62	m²	Window areas are subtracted from the individual areas specified in the "Windows" worksheet.	Exterior Wall - Ambient	0.117
9	Exterior Wall - Ground	B	0.00	m²	Temperature zone "A" is ambient air.	Exterior Wall - Ground	
10	Roof/Ceiling - Ambient	A	89.70	m²	Temperature zone "B" is the ground.	Roof/Ceiling - Ambient	0.117
11	Floor Slab	B	69.60	m²		Floor Slab	0.181
12			0.00	m²	Temperature zones "A", "B", "P" and "X" may be used. NOT "I"		
13			0.00	m²	Temperature zones "A", "B", "P" and "X" may be used. NOT "I"		
14		X	0.00	m²	Temperature zone "X": Please provide user-defined reduction factor (0 < f, < 1):	Factor for X	75%
						Thermal Bridge Overview	▼ (W/(mK))
15	Thermal Bridges Ambient	A	0.00	m	Units in m	Thermal Bridges Ambient	
16	Perimeter Thermal Bridges	P	0.00	m	Units in m; temperature zone "P" is perimeter (see Ground worksheet).	Perimeter Thermal Bridges	
17	Thermal Bridges Floor Slab	B	0.00	m	Units in m	Thermal Bridges Floor Slab	
18	Partition Wall to Neighbour	I	0.00	m²	No heat losses, only considered for the heat load calculation.	Partition Wall to Neighbour	
Total Thermal Envelope						Average Therm. Envelope	0.199

Area Input																Selection of the Corresponding Building Element Assembly	Nr.	U-Value [W/(m²K)]			
Area Nr.	Building Element Description	Group Nr.	Assigned to Group	Quantity	x (	a [m]	x	b [m]	+	User-Determined [m²]	-	User Subtraction [m²]	-	Subtraction Window Areas [m²]	=				Area [m²]	
	Treated Floor Area	1	Treated Floor Area	1	x (		x		+	107.00	-					=	107.0	From Windows sheet From Windows sheet From Windows sheet From Windows sheet From Windows sheet U-Value Exterior Door	0.851
	North Windows	2	North Windows														3.8		0.000		
	East Windows	3	East Windows														0.0		0.823		
	South Windows	4	South Windows														30.4		0.000		
	West Windows	5	West Windows														0.0		0.000		
	Horizontal Windows	6	Horizontal Windows														0.0		0.000		
	Exterior Door	7	Exterior Door	1	x (	1.10	x	2.25	+		-						2.5		0.81	
1	North Wall	8	Exterior Wall - Ambient	1	x (x		+	61.36	-						3.8	57.6	With Hairs	1	0.117
2	South Wall	8	Exterior Wall - Ambient	1	x (x		+	61.36	-						30.4	31.0	With Hairs	1	0.117
3	East Wall(Parti)	8	Exterior Wall - Ambient	1	x (x		+	43.05	-						0.0	43.1	With Hairs	1	0.117
4	West Wall	8	Exterior Wall - Ambient	1	x (x		+	43.05	-						0.0	43.1	With Hairs	1	0.117
5	Floor Slab	11	Floor Slab	1	x (x		+	69.60	-						0.0	69.6	Ground Hairs	4	0.181

Figure 62- Typical PHPP Calculation Sheet (Passivhaus Institut 2007)

the PHPP calculation for ease of data input or output such as Warms results sheet (Warm 2011). Accurate analysis results can be produced using relatively simple, but extensive numerical inputs rather than Virtual Environment Modelling software that require an accurate CAD model such as in Revit, Ecotect and IES. These numerical inputs are easily edited without making changes to a complicated three dimensional CAD model.

Outputs

The PHPP is used to demonstrate compliance with the criteria for Passivhaus certification process; Heat Load, Specific Heat Demand and Primary Energy Demand. However, the outputs are not just the data required for certification, but detailed information regarding all aspects of the building physics; heat loss, heat gain, cooling, ventilation, building fabric, electrical requirements etc. are produced. PHPP uses Energy consumption per unit floor area as the most fundamental indicator of energy efficiency measured in kWh/(m²a). This particular metric is used directly for energy rating purposes in the procedures of many other countries and low energy concepts such as Minergie.

Due to the open source formulae, all of the data and calculations accessible within Excel, any variation made can be traced through the various sheets to define its impact. The results and implications of different parameters are instantly updated on the related sheet and do not require external calculations or the generation of a report.

Further information on PHPP can be found in the methodology section and development of PHPP in the studies sections.

4.3.2. Virtual Environment Modelling

There are many programs that allow for the dimensions of a building to be read from a three dimensional model. These programs often either plugin to an existing program or can import geometry from other programs.

4.3.2.1. IES

The IES virtual modelling software suite is a example of dynamic building energy simulation software which take its inputs from a three dimensional model (Integrated Environmental Solutions 2014). The program also aims to be a one size fits all for building analysis rather than a design tool to develop and analyse ultra-low energy buildings. It has a range of analysis areas (University of Cambridge 2013):

- Solar
- Lighting & Day lighting
- Energy
- Cost Value
- CFD
- Mechanics
- Egress

This software does not require the user to have an advanced knowledge of *“computer programming or of the mathematics and equations that govern building physics”* (University of Cambridge 2013). The input and output process are carried out through a graphical user interface (GIU).

Integration with AutoCAD, Sketchup and Revit software is also available (Integrated Environmental Solutions 2013). This program operates using a ‘black box’ methodology where the user can view the input, output and transfer characteristics but has no knowledge of its internal workings (Wikipedia 2014).

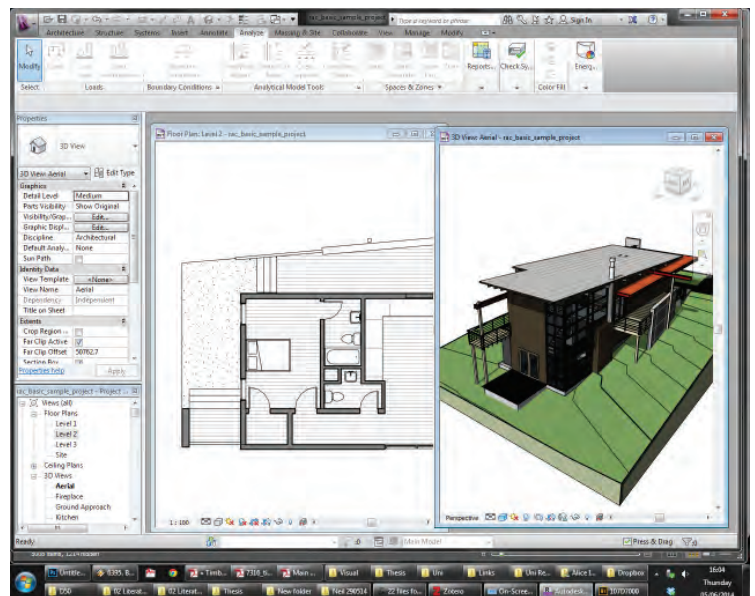


Figure 63- Revit 2013 Autodesk

4.3.2.2. Revit

[Figure 63]

The Revit Building Information Modelling (BIM) software’s standard package only supports basic building analysis tools (Autodesk 2014a). The inputs only define pre-set typical values for high and low insulation

levels as the package is unable to process precise fabric efficiency values. The results of the calculations therefore do not provide accurate information regarding heat loss and space heating energy use. Previously Autodesk offered Ecotect which aimed to offer detailed building analysis, however, this software appears to have been discontinued (Autodesk 2014b). The recently released Green Building Studio does have more inputs tailored for more detailed analysis however, use of this software would require the precise three dimensional Revit modelling of all of the building types (Autodesk 2014c). The majority of the calculations are performed using the Autodesk cloud server, which produces detailed report data, but the calculation methodology is not transparent or adaptable. Mistakes in user input may be more difficult to pin point due to the input methodology. Additionally precise individual elemental analysis may be more difficult due to calculation methodology.

4.3.3. Numeric Modelling Software and Virtual Environment Modelling Summary

Virtual Environment Modelling will more than likely become the industry norm with the programs such as Revit becoming more popular. This form of software removes the need for building metrics to be entered into a spread sheet or external program. However the translation of the model metrics into calculation input data is an opaque process. Errors in the model could be used in the calculation process and be difficult to identify. Virtual environment modelling software all rely on a 'black box' process methodology. Currently this methodology is not appropriate for the detailed analysis required for the research studies. With Numeric Modelling Software, accurate analysis results can be produced using relatively simple, easily editable, numerical inputs. In contrast to Virtual Environment Modelling which requires the production of a CAD model such as Revit, Ecotect and IES. In numeric modelling software, such as PHPP, results and implications are instantly updated within the program and do not require connection to a cloud server. PHPP allows the user to clearly identify energy gains and losses through a number of simple calculations allowing adjustment of variables with detailed understanding of the implications.

4.3.4. Critical Analysis of SAP & PHPP

Development

SAP and PHPP differ in their uses but both attempt to quantify the energy use of buildings. SAP is used to show compliance with current carbon emissions legislation and a variation will be used to provide compliance with the both proposed UK ZCH standards and most likely NEZB. The SAP's primary units are ($\text{kgCO}_2/\text{m}^2/\text{a}$) and depend on fuel type use but do not allow for a clear comparison of two building types with different fuel types. When SAP was initially developed in 1998, it was not designed for low energy housing certification. It was originally developed when the level of accuracy required for building performance was far lower due to significantly lower performance specifications therefore less sensitive to minor variations in specification and data entry.

In contrast PHPP is a design and certification tool developed exclusively for ultra-low energy buildings. The Passivhaus certification data is climate specific and building independent, the heating demand target and heating load are measured units per m². The targets and units (SSHD 15kWh/m²a, HL 10w/m²) allow for a comparative analysis method across any building using any fuel type. The building simulation tool (PHPP) has the facility for utilisation of detailed specific climatic data, unlike simulation tools such as SAP 2009 (BRE 2011e).

User Input

Both methodologies are examples of Numeric Modelling Software but have different input methodologies. SAP is less detailed but more user friendly than the PHPP's complex series of Excel Spread sheet tabs. SAP's accredited software's wizards, component databases, manuals and support enable the process to be more intuitive with less chance of major errors. However, SAP data entry errors are still common (Zero Carbon Hub 2010a, p.23).

PHPP allows for a flexible user data entry however, PHPP is not user friendly. PHPP requires a knowledge of complex building physics with little saved specification for componentry (Cutland 2012). There are few error checking mechanisms built into the Spread sheet and a single, complex manual translated from German. The PHPP requires 2,000 independent data entries across a range of 30 sheets (without the climate data set) to be entered in to the PHPP Excel file for full analysis (Passipedia 2013b). This makes the use of PHPP complex with a high margin for major errors or omitted data.

Specification Input

The UK Government relies on industry to provide product performance data in the form that is needed by SAP however, for certification the PHPP requires data accredited by the Passivhaus Institute, again this is another quality assurance step. It is recommended by PHI that components (such as MVHR and Windows) should be certified by the testing method within the Institute ensuring the products are tested using the same methods, producing an accurate benchmark specification (Passivhaus Institut 2012b).

Climate Data

The SAP tool is designed to compare two house types with each other irrespective of their location therefore does not give an accurate representation of the actual heating requirement or energy use in its' specific climate and location. SAP accredited software input is limited and the methodology relies on UK average climate data for heating requirements (BRE 2011a; Elmhurst Energy Systems 2013). Consequently, the omission of regional climate data negates the large UK regional climatic variations in the performance calculations. Therefore it is theoretically possible to design a ZCH with a much higher as built heat energy demand than estimated through SAP and significantly higher than an equivalent PHPP calculation due to the variations in climatic calculation methodologies.

The SAP methodology creates no requirement for regional design solutions or designs nuanced production areas across the UK as it does not consider regional climate data. Due to this nuanced designs would have no beneficial effect on the buildings overall energy performance rating. Therefore designs optimised for

solar orientation and context would require a third party program in order to analyse the design within the regional climate.

In contrast the Passivhaus concept has proven accuracy around Europe and relies on specific climate data requiring a regional design approach. This can be done using site-specific climate data which is available for the nine Scottish climatic zones available from BRE which is certified by the Passivhaus Institute (BRE 2011c). This allows for regional specificity of energy use, comparison between regions and analysis of climatically responsive designs. A similar range of climate data is published for SAP, however, the input of this data requires specialist programming knowledge and access to developer versions of the accredited software packages to support alterations to the climate data (BRE 2011a).

Assumptions

The Passivhaus methodology differs from the SAP methodology in that the simulation software used assumes lower internal gains, considers linear thermal bridging and regional climatic data (Tuohy & Langdon 2009). The “tool [PHPP] is reckoned to produce more accurate estimates of energy consumption than the UK’s SAP methodology, and to provide better estimates of thermal comfort, air quality and overheating risk” (Cutland

Survey Details

SAP rating	79 C	CO ₂ Emissions	2.12	DER	23.09 kgCO ₂ /yr/m ²	Reduction	FEE	62.0	ZC8	N/A
Environmental	80 C	General Requirements Compliance	Pass	TER	28.96 kgCO ₂ /yr/m ²	20.27 %	HLP	1.37	Energy Cost	£558.10
CFSH Results		ENE1 Credits	N/A	ENE2 Credits	N/A	ENE7 Credits	N/A	CFSH Level	N/A	

Property: Example 3 End Terraced House 10 Main Street Lutterworth LE17 4XX

RRN:

Recommendations

Low cost measures	Typical cost	Typical savings per year	Energy efficiency	Environmental impact	Result
<input checked="" type="checkbox"/> Low energy lights			0	0	Already installed

Further measures

<input checked="" type="checkbox"/> Solar water heating	£4,000 - £6,000	£80	B 82	B 83	Recommended
<input checked="" type="checkbox"/> Photovoltaic	£9,000 - £14,000	£233	B 91	A 92	Recommended
<input checked="" type="checkbox"/> Wind turbine			B 91	A 92	SAP increase too small

Improved Dwelling Results

Actual SAP ratings:	79 C
Environmental Ratings:	80 C
Dwelling Emission Rate:	23.09 Pass
Target Emission Rate:	28.96

Reports

Report	Copies	Report	Copies
<input checked="" type="checkbox"/> Block Compliance		<input checked="" type="checkbox"/> Summary Information	
<input type="checkbox"/> Code for Sustainable Homes		<input type="checkbox"/> Survey Notes	
<input checked="" type="checkbox"/> Compliance Information		<input type="checkbox"/> Thermal Bridging	
<input type="checkbox"/> Condensation Risk		<input type="checkbox"/> U-value Calculation	
<input checked="" type="checkbox"/> Full SAP Calculation		<input type="checkbox"/> Cover Sheet	
<input checked="" type="checkbox"/> Predictive Energy Assessment (PEA)		<input type="checkbox"/> Combine Reports	

Report Issue Date: Today

Action: ☐ Print ☒ Preview ☐ Save as PDF

Proceed

Preview debug report Preview EPC Generate EPC

Save Save & Close Cancel

Figure 64- SAP Results Elmhurst SAP 2009

2012). This view is shared in Germany, “Passivhaus is described as reliable (DA), and performance variations between identical dwellings in use are supposed to be smaller in the case of Passive Houses than in “normal” dwellings” (Müller & Berker 2013).

Display of Results

The SAP calculation methodology relies on isolated user input, with the only immediate indication of the impact of changes to specification been shown in carbon emissions: DER & TER (kgCO₂/yr/m²), heating costs (£), CO₂ emissions and SAP rating [Figure 64] (Elmhurst Energy Systems 2013). The detailed calculations are not presented and a detailed report is only viewable once a full calculation has been performed. This report will only display totals and summaries rather than full calculations.

In comparison the PHPP calculation methodologies use more direct and clear display of results which illustrate the impact of design changes without the requirement to produce a finalised results page. In PHPP the user has the ability to view all of the implications of the specification change on the different calculation sheets within the Excel Spread sheet, such as heat loss figures, space heat demand, heating, cooling load, etc.

4.4. Low Energy Scottish Housing Exemplars

Currently there are only a handful of organisations, professionals and built examples that address the requirement for low energy housing. There is also comparatively little generic guidance and best practice available on this topic. This section provides an overview of current Scottish Practice, mentioning some of the key examples and figures in Scotland active in this area.

4.4.1. Guidance

Much of the available research and design guidance such as *Best Practice in New Housing –A Practical Guide* and *Sustainable Housing Design Guide for Scotland* concentrates on specification rather than physical attributes of the site and form of the building (Stevenson 2000; Energy Saving Trust 2005). Scottish Ecological Design Association (SEDA) have limited guidance documents regarding low *Designing for Deconstruction*, *Toxic Chemical Deduction* and *Airtightness* and are currently developing a ‘*Green Building Database*’ (SEDA 2013). SUST is the sustainable a division of A+DS. They have a variety of case studies and links on their website, but the majority of the information is examples of best practice (Architecture and Design Scotland (A+DS) 2014a). The ‘*Green Directory*’ run in collaboration with SEDA contains links to other organisations (Architecture and Design Scotland (A+DS) 2014a; SUST 2014). The *Greener Homes Prospectus* aims to support the delivery of the Scottish Government’s Sustainable Housing Strategy by illustrating examples of new build and retrofit projects which are more sustainable in Scotland (Scottish Government 2012a; Scottish Executive 2013g). The majority of the houses utilise suburban housing forms with increased thermal specification through modern methods of construction some of which utilise renewable technologies. Other examples use a fabric first approach to increase the fabric performance before adding renewables. However these examples do not appear to be designed to maximise solar gain and their conceptual approach is unclear. The

majority of the demonstrator project case studies take the form of large scale development. The others are overviews of large scale development including The Commonwealth Games, Housing Innovation Showcase, BRE Innovation Park and Riccarton Eco-Village and Living Laboratory are mentioned. The Glasgow House by PRP is the only single house featured which is aimed to give a two-thirds reduction in typical energy costs. There are only two ultra-low energy, Passivhaus related topics. The first is the Dormont Park Estate development which is discussed below. The second is the Beattie Passive Build System which was used to construct four three bedroom houses built in Dunfermline. These homes were the first to reach Scotland's Gold Standard (highest defined standard), but are not certified as Passivhaus. The building system however was the first UK company to be awarded certification by the Passivhaus Institut as a 'Passivhaus continually insulated building system' (Passivhaus Trust 2012). The *Greener Homes Prospectus* is one of the few documents which aims to showcase the range of Scottish energy efficient homes. However the typical developer style designs with improved fabrics are discussed in more detail than other more innovative examples of design. This possibly reflects the limited ambition in this field in Scotland.



Figure 65- Gökyay Deveci, Model-D House timber (Architecture and Design Scotland (A+DS) 2014b, P8)

4.4.2. Practice

One of the leading ultra-low energy architects in Scotland is Gökyay Deveci who is a professor at Robert Gordon University, Aberdeen. He has produced numerous high performance one off buildings across Scotland including ones to the Passivhaus standard featured on the Scottish Government's *Inspirational Designs* website. Deveci was the designer of the multi award winning Dunoon development of fifteen low cost low energy homes for Fyne Homes



Figure 66- White Hill Design Studio, Dormont Estate, Lockerbie

(Architecture and Design Scotland (A+DS) 2014c). This development included the first Passivhaus in the UK, Tigh-Na-Cladach. Deveci also works on ultra-low energy sustainably sourced buildings with the award winning Model-D house and the Midmar Passivhaus. The Model D house is designed to require minimal maintenance and is made almost entirely of Scottish grown timber (Architecture and Design Scotland

(A+DS) 2014b).[Figure 65] The house was designed with a Passivhaus fabric specification but does not appear to have been certified (Scottish Executive 2012f).

The Dormont Park estate development by White Hill Design Studio, is sited in Lockerbie and is a development of eight two and three bedroom houses all certified to the Passivhaus standard (White Hill Design Studio 2014). The architect claimed in a recent presentation

that the houses emit an estimated 70% less CO₂ than a similar house built to current building regulations.

The houses have been subject to a post occupancy evaluation which confirmed their energy performance (Glasgow School of Art & Sharpe 2011). These houses integrate traditional features such as dormer windows and chimneys in order to fit in with the existing estate buildings. This development has been featured in the Scottish Government's *Inspirational Designs* website for the relationship to context, energy performance and use of designing streets (S. A. H. Scottish Government 2012b). However the proportions of these buildings appear to reflect suburban houses rather than traditional cottages [Figure 66]. Locate Architects have worked in collaboration with other architects and contractors on a variety of ecological building construction projects which tend to be in rural areas (Morgan 2014). The firm built the Craigrothie Passivhaus in Dairsy which was developed in conjunction with Graham Drummond, when certified it was the smallest certified Passivhaus in Europe (Passivhaus Trust 2013a). [Figure 67] John Gilbert Architects focus on sustainable architecture and have been involved in research exercises with the Forestry Commission to build houses with Scottish timber which also featured in the Scottish Housing Expo (Gilbert 2009; John Gilbert Architects et al. 2006).



Figure 67- Locate Architects, Dairsy, Craigrothie House

4.4.3. Innovative Development

Throughout Scotland there have been examples of innovative sustainable housing and low energy housing

development. The BRE have developed a Scottish Innovation Park Ravenscraig which opened in 2012.

However the park only contains three houses; the Apple Green House, Resource Efficient House and Refurbished house (BRE 2012). The house with the highest energy performance is only built to the Scottish Gold standard which defines a SSHD of 30 kWh/m² for houses and a 60% reduction on 2007 carbon emissions (Scottish Executive 2013h). A similar development with more examples of housing is the Dunfermline



Figure 68- The Dunfermline Housing Innovation Showcase (SUST & A+DS 2012)

Housing Innovation Showcase, also opened in 2012 and is a joint venture between the Kingdom Housing Association and Fife Council (Scottish Executive 2012e, p.54; SUST & Architecture and Design Scotland (A+DS) 2012)[Figure 68]. The showcase consists of 27 homes for rent as a part of a larger masterplan which development demonstrate 10 different Modern Methods of Construction. The Scotland's Housing Expo held in Inverness in 2010 was described to have showcased "*master planning, passive energy techniques and new building technology in low carbon building design*" (Scottish Executive 2013c). The original funding model for the Expo was deemed unrealistic with the event of the financial crisis (BBC 2011b). Savings were made through the reduction of energy saving measures and low carbon technologies. This had a major impact on some of the performance of the buildings finally realised. The planned Passivhaus development did not receive the Passivhaus certification and many of the proposed low carbon technologies were omitted from designs due to cost cutting.

There are a limited number of low and ultra-low energy houses in Scotland. As discussed previously there are currently only six developments in the Passivhaus database with another two newly certified (passivhausprojekte 2014; Passivhaus Trust 2013b; Maguire 2013).

The lack of examples and research could be attributed to a number of factors.

- Lack of ultra-low energy legislation targets- (Scottish ZCH standard undefined)
- Increased initial build and certification costs (Passivhaus)
- Lack of skilled workmanship (airtightness)
- Impact of the financial crisis on developers and availability of grants.

4.5.UK Passivhaus Case Studies

The following case studies were developed in the early stages of the research. These were among the first UK Passivhaus development in the UK. The specifications defined the initial specifications of the

Welsh Passivhaus

Basic data

Country: United Kingdom
Region: Wales
City: Ebbw Vale, Blaenau Gwent
Postal / ZIP Code: NP23 6YL
Object name: Welsh Passivhaus
Object state: Under construction
Start of construction: 2010
Building completion: 2010
Object type: Model house I example house
Building structure: New building
Energy efficiency: Passive House
Construction: Timber construction
Number of units: 1
Urban situation: Suburban development
Gross floor area: 87 m²
Number of storeys proper: 2

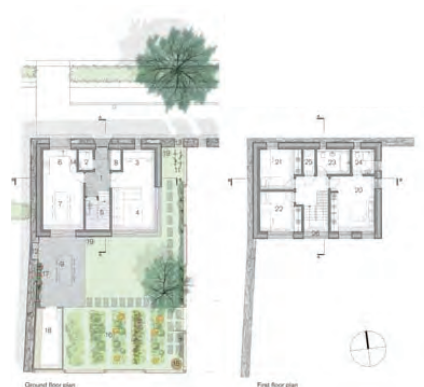


Project description:

The Welsh Passivhaus is inspired by the simple forms of traditional cottages. A protecting drystone wall encircles the street elevation at ground level providing a strongly defined edge to the site. Deep window reveals improve the privacy of the ground floor walls. On the garden side, the wall soaks up the summer sun, dissipating heat in the cooler evenings. On the first floor the timber cladding will weather to a soft silver grey. The sheltered timber of the garden elevations remains honey coloured. Entering the house the central stairwell divides the ground floor into two well proportioned spaces. A large south facing window above the stairs brings light flooding into the entrance hall.

Key figures PHPP

Quality approved Passive House, Dr. Wolfgang Feist: yes
Passive House verification method: PHPP - Passive House Planning Package
Treated floor area: 87 m²
Annual heat demand: 12.9 kWh/(m²a)
Total primary energy demand: (DHW, heating, cooling, auxiliary and household electricity): 78 kWh/(m²a)
Heat load: 10.7 W/m²
Airtightness (Calculated acc. to PHPP): 0.6 1/h
Airtightness (Pressurization test I airtightness measured): 0.2 1/h



Building envelope

Exterior wall (construction): Timber frame with 280mm of mineral wool insulation, 100mm service void on inside with wood fibre insulation and a 100mm rigid wood fibre insulation on the outside.

Exterior wall U-value (Specific average value) : 0.095 W/(m²K)

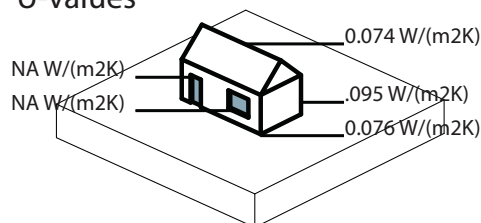
Roof (construction): 560mm mineral wool insulation

Roof U-value (Specific average value) : 0.074 W/(m²K)

Basement floor I floor slab (construction): 480mm EPS insulation under concrete slab

Basement floor I floor slab U-value (Specific average value) : 0.076 W/(m²K)

U-values



Building Services

Ventilation

Type of ventilation system: Building centralised with heat recovery

Heat generation

Solar thermal hot water: yes

Heat generation: Fossil fuel

Source of energy: Condensing boiler

Heat storage: Combined solar storage

Heat distribution: Radiators

Electricity demand (household applications)

Generation of electricity (user application): Photovoltaics

Description of generation (electricity): Mains electricity and photovoltaics (2.52kwp)

<http://www.passivehousedatabase.eu/>

Dunoon

Basic data

Country: United Kingdom
 Region: Scotland
 City: Dunoon
 Postal / ZIP Code: PA29 7QL
 Object name: Dunoon PassivHaus
 Object state: Complete
 Start of construction: 2009
 Building completion: 2009
 Object type: Model house I example house
 Building structure: New building
 Energy efficiency: Passive House
 Construction: Timber Construction
 Number of units: 1
 Urban situation: Rural
 Gross floor area: 88 m²
 Number of storeys proper: 2



Project description:

Townhouse buildings, low energy houses in the "Affordable Housing Scheme" dargestellt the terrace house was built as a passive house. The building was built in a special form of the (Scottish) public housing, a portfolio that integrates financial future residents, so we planned very efficiently, according to the energy and the associated economic demands.

Key figures PHPP

Quality approved Passive House, Dr. Wolfgang Feist: yes
 Passive House verification method: PHPP - Passive House Planning Package
 Treated floor area: 88 m²
 Annual heat demand: 21 kWh/(m²a)
 Total primary energy demand::99 (DHW, heating, cooling, auxiliary and household electricity):
 ...kWh/(m²a)
 Heat load: 10 W/m²
 Airtightness (Calculated acc. to PHPP): 0.6 1/h
 Airtightness (Pressurization test I airtightness measured): 0.2 1/h

Building envelope

Exterior wall (construction): Cavity Wall, OSB 30 cm, I-studs, mineral wool (035) OSB 5 cm, PU Insulation (023) Plasterboard
Exterior wall U-value (Specific average value): 0.095 W/(m²K)
Roof (construction): Slate coverage Sarking Boards 30 cm I-studs + mineral wool (035) OSB 5 cm, PU Insulation (023) Plasterboard
Roof U-value (Specific average value): 0.095 W/(m²K)
Basement floor I floor slab (construction): Insulated concrete slab 12.5 cm Concrete slab 20 cm XPS Insulation (032)
Basement floor I floor slab U-value (Specific average value): 0.15 W/(m²K)

Window frame:(Specific description, manufacturer, product name) Inter standard edition Aluminum clad wood frame (rotation / tilt and fixed lights) wood aluminum window frame (partly fixed glazing) Velux roof window

Glazing:(Specific construction, manufacturer, product name): Saint-Gobain, triple glazing, 6b/10g/5/10g/b6 filled with argon - that is 6mm glass, coating, 10mm argon, 5mm glass, 10mm argon, coating, 6mm glass.

U_g -value = 0.8 W / (m² K)

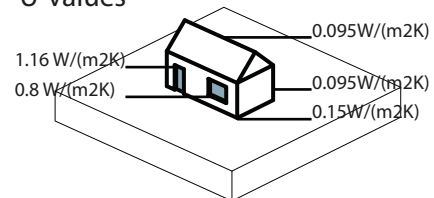
g-value = 51%

(all windows) (Specific averagevalue) : 0.8 W/(m²K)

Entrance door:(Specific description, manufacturer) Inter Standard Edition

U_d-Value entrance door: 1.16 W/(m²K)

U-values



Tigh-na-Cladach, Bullwood Road
 2 Bedroom
 Plot 15

Building Services

Ventilation

Type of ventilation system: Paul, thermos 200 DC compliant passive house mechanical ventilation heat recovery unit (WRG 92%)

Heat generation

Solar thermal hot water: yes

Domestic Hot Water: Collector area (4.6 square meters Velux M08 collector

Heat generation: Air source heat pump and heat recovery

Source of energy: Electric

Heat storage: 300-liter tank with electric heating

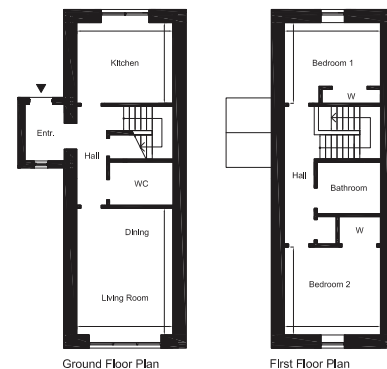
Heat distribution: ...

Electricity demand (household applications)

Generation of electricity (user application): ...

Description of generation (electricity): ... (...kwp)

passivhausprojekte.de



Denby Dale Passivhaus

Basic data

Country: United Kingdom
Region: West Pennines
City: Denby Dale
Postal / ZIP Code: HD8 8RP
Object name: Denby Dale Passivhaus
Object state: Completed
Start of construction: 2009
Building completion: 2010
Object type: Single-family detached house
Building structure: New building
Energy efficiency: Passive House
Construction: Masonry construction
Number of units: 1
Urban situation: Suburban development
Gross floor area: 104 m²
Number of storeys proper: 2



Project description:

The Denby Dale Passivhaus has pioneered the combination of low energy Passivhaus methodology with standard British cavity wall construction and building materials and is the UK's first cavity wall Passivhaus. Built for private clients as a home for their retirement to a tight budget of 141K, the project was designed and built by Green Building Company - the construction division of Green Building Store. To get cavity wall to perform to Passivhaus standard the building team had to develop unique design details. For more information on the Denby Dale Passivhaus and to register for a free 40 page pdf technical briefing go to www.greenbuildingstore.co.uk/denbydalehouse

Key figures PHPP

Quality approved Passive House, Dr. Wolfgang Feist: yes
Certifier: UK PETER WARM - Low Energy Building Practice
Passive House verification method: PHPP - Passive House Planning Package
Treated floor area: 104 m²
Annual heat demand: 15 kWh/(m²a)
Total primary energy demand: (DHW, heating, cooling Auxiliary and household electricity): 83 kWh/(m²a)
CO₂-Emission (PE-figure for DHW, heating and auxiliary electricity): 17 kg/(m²a)
Heat load: 10 W/m²
Heat load ≤ 10 W/m²: yes
Airtightness (Pressurization test I airtightness measured): 0.34 1/h

Building envelope

Exterior wall (construction): Gypsum Plaster Dense Concrete Block Cavity Fill Mineral Wool - 300mm Sandstone

Exterior wall U-value (Specific average value): 0.11 W/(m²K)

Roof (construction): Plasterboard Mineral Wool - 500mm

Roof U-value (Specific average value): 0.1 W/(m²K)

Basement floor / floor slab (construction): Screed Knauf Polyfoam - 225mm

Basement floor / floor slab U-value (Specific average value): 0.1 W/(m²K)

Window frame:(Specific description, manufacturer, product name) Ecopassiv triple glazed FSC 100% timber windows

Glazing:(Specific construction, manufacturer, product name) Triple glazed Uw-Value installed (all windows) (Specific average value) : 0.8 W/(m²K)

Entrance door:(Specific description, manufacturer) Ecopassiv triple glazed FSC 100% timber doors
Ud-Value entrance door: 0.8 W/(m²K)

Building Services

Ventilation

Type of ventilation system: Building centralised with heat recovery

PHI-certified ventilation appliance: yes

Ventilation (heat recovery unit): PAUL Thermos 200 MVHR

Heat generation

Heating system: Vaillant Eco-Tec 612 (4.8kw)

Solar thermal hot water: yes

Heat generation: Fossil fuel

Source of energy: Condensing boiler

Heat storage: Combined solar storage

Heat distribution: Radiators

Electricity demand (household applications)

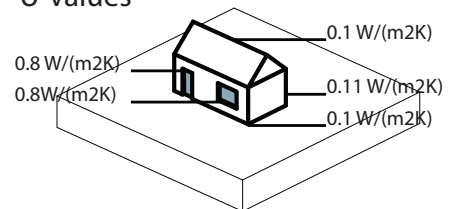
Description of generation (electricity): Mains electricity and photovoltaics

Concept of lightning savings: Low energy LED lighting in most areas

<http://www.passivehousedatabase.eu/>

D:\Docs\Work\Uni\PHd\Research\Standards and Strats\Passive Haus\Denby Dale Passivhaus

U-values



Ranulf Road

Basic data

Country: United Kingdom
Region: South East England
City: London
Postal / ZIP Code: NW2 2BT
Object name: Ranulf Road, London
Object state: Completed
Start of construction: 2009
Building completion: 2010
Object type: Single-family detached house
Building structure: New building
Energy efficiency: Passive House
Construction: Timber construction
Number of units: 1
Urban situation: City development
Gross floor area: 100 m²
Number of storeys proper: 2



Project description:

Ranulf Road, London's first Passivhaus was completed in April 2010. The project is a **120sqm** single family house split over 2 floors. The primary objective of this project is to achieve a comfortable home for a young family, whilst minimising energy consumption. It contains two wildflower meadow roofs and a south facing garden enclosed by an ivy fence to increase local biodiversity. Healthy air and water quality is prioritised by using non-toxic materials; heat recovery ventilation and water filtration for drinking and bathing. Mains water use is supplemented by an underground water harvesting tank providing water for irrigation.

Key figures PHPP

Quality approved Passive House, Dr. Wolfgang Feist: yes
Passive House verification method: PHPP - Passive House Planning Package
Treated floor area: 100 m²
Annual heat demand: 13.3 kWh/(m²a)
Total primary energy demand: (DHW, heating, cooling, auxiliary and household electricity): 90 kWh/(m²a)
Primary energy demand: (DHW, heating and auxiliary electricity) 43 kWh/(m²a)
CO₂-Emission (PE-figure for DHW, heating and auxiliary electricity): 20 kg/(m²a)
Heat load: 9 W/m² Airtightness (Pressurization test I airtightness measured): 0.4 1/h

Building envelope

Exterior wall (construction):

Lower retaining external wall: 200mm caltite concrete, 240mm timber studs with mineral wool, 15mm OSB, airtightness membrane, 100mm service void filled with wood fibre insulation.

Upper external wall: larch cladding on battens, building paper, 15mm fermacell panels, 280mm timber studs with mineral wool, 15mm OSB board, airtightness membrane, 100mm insulated service void.

Exterior wall U-value (Specific average value) : 0.11 W/(m²K)

Roof (construction): Flat roof: massive wood panels, 280mm PUR, 120mm mineral wool insulation, wildflower meadow roof. Pitched roof: 380mm mineral wool insulation in a timber frame construction, wildflower meadow roof.

Roof U-value (Specific average value) : 0.11 W/(m²K)

Basement floor / floor slab (construction): In-situ concrete floor slab. Timber frame ground floor build up - 140mm timber beams with wood fibre insulation between. Air tightness membrane laid over beams. 100mm service void created with 100mm timber beams, wood fibre insulation between. Floor finish - 16mm engineered oak floor boards.

Basement floor / floor slab U-value (Specific average value) : 0.1 W/(m²K)

Basement: No basement

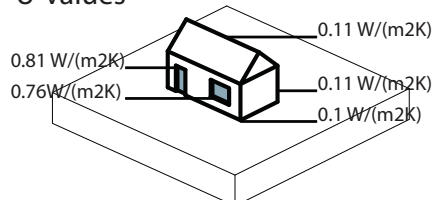
Window frame: (Specific description, manufacturer, product name) Triple Glazed German windows with warm edge spacer (psi 0.039W/mK)

Uw-Value installed (all windows) (Specific average value) : 0.76 W/(m²K)

PHI-certified entrance door: yes

Entrance door: Triple glazed (Specific description, manufacturer) U_d-Value entrance door: 0.81 W/(m²K) Impressum Kontakt

U-values



Building Services

Ventilation

Type of ventilation system: Building centralised with heat recovery

PHI-certified ventilation appliance: yes

Ventilation (heat recovery unit): PAUL Thermos 200 DC

Heat generation

Heating system: Heat supplied through the ventilation system with towel radiators in the bathrooms for additional comfort.

Domestic hot water system: Gas condensing boiler and 3 sqm of solar panels.

Solar thermal hot water: yes

Heat storage: Combined solar storage

Electricity demand (household applications)

Concept of lightning savings: Low energy LED and fluorescent lighting throughout.

<http://www.passivehousedatabase.eu/>

prototype dwelling used in the research studies. The majority of the information was taken from *pass-net*, *net* and *passivhausprojekte.de* fact sheets. (PassNet 2010b; PassNet 2010a; PassNet 2010c; Deveci 2011; passivhausprojekte 2010).

4.6. Ultra-Low Energy Housing Summary

There is a requirement for the lowering of greenhouse gas emissions (included CO₂) and energy use with legislation and targets at worldwide, European, UK and Scottish levels. The ZCH legislation in the UK comes from the requirement for NZEB by the end of 2020 defined by the EPDB in 2010. The current Scottish Building Standards still do not define approach for the ZCH standard (Platinum). The initial target for ZCH by 2016/17 is not mentioned in the update in legislation and appears to be under threat (Scottish Executive 2013a). This will undoubtedly have a knock on effect for meeting the 2020 NZEB target. Rather than the original intention of developing a Scottish specific definition and related research for ZCH, the Scottish Government is now referencing some of the approaches taken in the ZCH for England and Wales such as the carbon offsetting approach: *Allowable Solutions* (Scottish Executive 2013a). This method proposes that carbon saving measures paid for by a developer could be implemented elsewhere, not effecting the original development. The final definition of Allowable Solutions is still unclear, however this offsetting principle is criticized for devaluing the building energy performance (Kibert & Fard 2012, p.634). The current-cost effective method for UK ZCH involves a minimum fabric efficiency standard (FEES) and significant contribution from renewables and carbon offsetting (Zero Carbon Hub 2014c). The FEES standard determines a minimum space heating requirement of a detached dwelling as 46 kWh/(m²a) which is far higher than that of Passivhaus at 15 kWh/(m²a) (Zero Carbon Hub 2014c). Due to the harsh climates and expensive fuel costs in rural areas a method that prioritises reductions in running costs over the use of technology and carbon offsetting may be more appropriate.

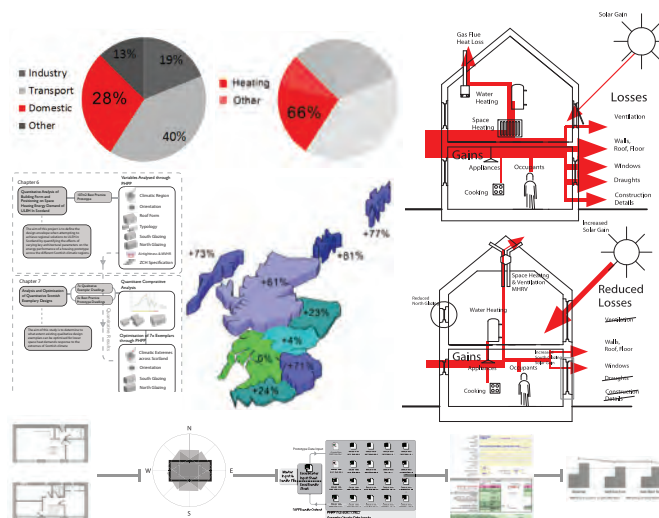
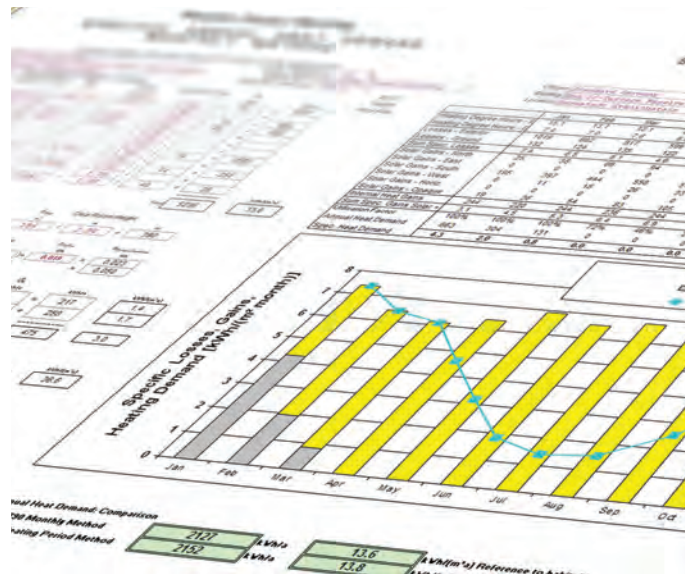
The space heating requirement and carbon emission are determined by SAP which is the Government approved methodology for the energy rating of dwellings. The methodology relies on UK average climate data for the majority of its compliance calculations. Therefore SAP results achieve climatic neutrality across the UK. Consequently this means regions that have poorer than UK average climatic conditions will have higher actual carbon emissions and receive lower performance levels than estimated. Due to the lack of requirement for the design of regional solutions in legislation, there is also a lack of guidance or research on the effect of regional climates across the UK. In contrast PHPP requires site or region specific climate data to illustrate compliance with the Passivhaus ultra low energy concept, proven throughout Europe. Due to carbon offsetting defining the FEES specification and use of average climate in SAP the actual carbon emissions of a house in rural Scotland could be far higher than the original aim of zero carbon. The main units generated by SAP for building performance analysis for compliance with UK's building regulations and ZCH is measured in carbon emissions per year (kgCO₂/m²/annum). The UK is the only nation to use units of carbon emissions and the SAP methodology so comparison with other low energy approaches is difficult. Other European nations and energy concepts use energy (kWh/(m²a)) as a primary unit of measuring building performance.

It is difficult to point towards exemplary low energy and high design quality in rural Scotland developed by the mass-market housing sector. Examples found the *Greener Homes Prospectus* are mostly suburban models with upgraded specification. One exception although not designed for the mass market is development at Dormont Estate. The eight Passivhaus certified rental properties are similar in scale to a small mass market development. These illustrate the Passivhaus fabric first approach that results in a significant reduction in heating costs that are intended to reduce fuel poverty (Passivhaus Trust 2013a). The performance of these buildings in the rural setting has been proven to give the occupants significant savings in energy bills and to work effectively in the Scottish climate (Glasgow School of Art & Sharpe 2011). The design of these houses also attempts to tie into the existing rural estate context.

The developers reliance on standardised suburban housing models and layouts are not appropriate for rural areas, nor for ultra-low energy housing. There is currently a lack of holistic thinking when designing mass-market rural housing in Scotland which is impeding the desire to reduce its energy demand and improve its design aspirations. Mass market rural housing designed to consider both architectural design and low energy performance could significantly increase its quality and energy efficiency.

METHODOLOGY

Chapter 5



5. METHODOLOGY

The methodology chapter firstly summarises the research problem and gaps in current knowledge defined in the literature review. It defines the research scope, aims and objectives. It then describes the rationale for the research in terms of defining a Passivhaus standard ULEH prototype and the use of PHPP in quantifying the energy balance of this prototype across regional climate areas in Scotland. The principle contribution to new knowledge is outlined in relation to the requirements in current practice. The requirement and steps for a methodological improvement to PHPP is discussed and outlined. The final section of the chapter introduces and outlines the methods and aims of the two analytical research studies which follow this chapter.

5.1. Summary of the Research Problem

There is a desperate need for houses that are affordable to live in and affordable to heat in many rural areas. There is also a future requirement for significant numbers of new housing in rural areas. The heating requirement of houses uses around 60% of the total energy use of homes in the UK, this figure is likely to be higher for homes in rural Scotland. However there is currently a lack of direction in the future of Scotland's ZCH target. It is unlikely that mass market will provide any increases in performance other than what is necessary to comply with the building regulations in the run up to the NZEB target in 2020. There is also a lack of design quality in the mass market housing sector that is defined in planning guidance. Almost all planning guidance and planning regulations are attempting to move away from suburban style development in rural Scotland. Alternative examples or development models are rarely put into practice and few if any of these are designed and modelled around low energy principles. Local authority planning departments rarely enforce their aims with planning refusals so there is little incentive for developers to change from the suburban model and planning regulations only give superficial guidance and have limited power to support low energy and sustainable settlement morphologies. Consequently it is likely that housing developers will continue to develop homes which only meet minimum energy requirements and utilise tried and tested housing models unless quantitative knowledge leading to viable, alternative methods are developed.

There will be a significant number of new houses required in rural Scotland over the next two decades. It is estimated that the population of Scotland will increase by 10% in 2035 and with an increasing trend in rural migration there will be a significant number of new houses needed in rural Scotland over the next two decades to meet this demand. Rural areas are projected to have a proportionally higher increase in housing compared to urban areas which could be as high as 32% in some rural regions. There is also a current requirement for affordable rural housing with affordable running costs as around 38% of the rural population are fuel poor. This figure rises in remote rural areas such as Orkney where almost half the population are in fuel poverty. This can be attributed to numerous factors, the low numbers of social housing combined with the high cost of renting or buying housing due to the large proportion of second/holiday homes. The performance of housing and regional climate variation are significant factors with a harsher than UK average climate, the dependency on costly off-grid fuel sources and, a high proportion of detached dwellings with poor energy efficiency ratings leading to increased space heating energy use.

The considered use and reinterpretation of appropriate vernacular and traditional features, materials and forms that are specific to regional context can be very successful in Scottish architecture as illustrated through the last 100 years or so. This originates with the formal relationship of arts and crafts architects such as Macintosh, continuing in the modernist period with Morris & Steedman, Robert Matthew and Basil Spence. This is still evident through the work of small rural contemporary practices such as Dualchas and Rural design who are employing critical regionalist design principles through appropriate reference of traditional forms, details and materials. The considered use of traditional materials is creating a recognised improvement to development of privately commissioned housing in rural areas. However, many contemporary examples of high quality contextual residential design are generally designed with an instinctive approach to low energy considerations rather than a quantitative low energy approach such as ZCH or Passivhaus. In contrast much of mass market development uses suburban housing models and development layouts in defiance of the majority of planning guidance. These approaches often use ill-considered neo-traditional standardised 'kit' designs in order to meet minimum planning requirements. To date, there has been little consideration of orientation, density, lifestyle, contextual response or the development of appropriate identities in the majority of mass-market residential developments in rural Scotland during the last 40 years. Only a handful of these developments have attempted to fully embrace planning and design quality agendas such as the 2010 Scottish Housing Expo.

In addition, there are increasing pressures and targets for new housing to reduce CO₂ emissions contributing 27% of the final-energy requirements in Europe, in the UK space heating accounts for 60% of this energy. To address this the EPBD defined the target for NZEB by the end of 2020, and in response to this the UK has created the ZCH legislation. This requires all new Scottish homes to be Zero Carbon 'by 2016/17, if practical', but the Scottish ZCH legislation has yet to be fully finalised (Scottish Government 2007a, p.7). The UK definition of ZCH currently includes carbon offsetting rather than a focus on optimisation of energy use and this has been criticized for de-valuing the building energy performance. The current-cost effective method for ZCH is based on the FEES standard which sets a minimum space heating figure above other ultra-low energy approaches. The UK methodology for the energy rating of dwellings, SAP uses UK average climate data for the majority of its calculations including heating requirement. This has the effect of standardising performance estimation across the UK which will underestimate heating requirements in climates with harsher climates than the UK average such as Scotland's rural regions. The UK energy legislation does not require regional solutions, therefore there is no guidance or research available for the design of low energy housing specific to regional areas in Scotland. There are only a few examples of published research on sustainable building design and little evidence of broader fundamental research in this area. Guides have been published looking at sustainable design but they do not generally focus specifically on achieving ultra-low energy performance. Over the last ten years the specification of residential buildings has seen improvements to fabric performance standards in line with contemporary legislation. However much of the current rural housing development does not aim to improve on mandatory energy efficiency standards defined in current Scottish Building legislation irrespective of actual performance caused by differing climatic conditions.

The aims of current UK planning and building standards legislation is to promote ultra-low energy, sustainable

buildings with high design quality aspirations. There is a wealth of guidance on good design practice and suggestions of best practice examples, however there are few examples of low energy guidance for Scotland. The optional PAN guidance and regional planning advice defines best practice in design only have simplistic, rough guidance for energy efficiency, appropriate on-site layouts and orientations but no detailed guidance beyond this. Residential examples in Scotland demonstrate strengths in high quality design or ultra-low energy, but these are rarely addressed together. Passivhaus examples can arguably cover both quality design and low energy performance such as the Plumberswood house (2011, Gaia architects), Kirsty Maguire's Farmhouse (2013) and Gökay Deveci's Dunoon Passivhaus (2009) but, they are expensive, one off developments (Passipedia 2012a; Passivhaus Trust 2013c; Passivhaus Trust 2013a; Maguire 2013). They are not without their own issues highlighted through post occupancy evaluations such as the poor performance from the MVHR in Dunoon (Tuohy et al. 2012; Butler & ARUP 2013). A significant reduction in heating costs will reduce the possibility of fuel poverty due to the decreased reliance on costly fossil fuels for space heating. Dormont Estate is a low cost, award winning Passivhaus development made possible by the '*Rural Homes For Rent pilot grant scheme*' (Scottish Executive 2008e). Despite winning design awards their appearance still reflects a developer style model (Passivhaus Trust 2013b; S. A. H. Scottish Government 2012b). This model's performance and affordability is currently the most successful and relevant direction for ultra-low energy homes development in Scotland.

Currently there is little knowledge or guidance on how to design homes with lower space heating needs for Scottish regions other than with generically applicable fabric improvements. There are only limited resources and no quantitative guidance on the design of ultra-low energy housing in Scotland as a whole. In rural areas in particular, there is a need for more research into the effects of regional climatic variations and design on performance of low energy housing. This is due to the significant variation of Scottish climates with harsh climates tending to be more common in rural areas leading to higher fuel costs affecting the affordability and the subsequent long-term sustainability of many rural settlements. There is a need to quantifiably illustrate the energy saving potential through on site placement and alterations to formal variables such as building form, typology, spatial organisation and glazing areas to reduce housing energy requirements in Scotland. The future of the regulations and testing methodologies are unlikely to require regional solutions that require fabric first principles in the near future, therefore guidance will be limited and uptake on regional solutions will be limited unless significant variation is quantitatively illustrated. Consequently there is a need to develop approaches that suggest how best to combine good quality contextual design with low and ultra-low energy in rural Scotland ahead of the legislation.

5.2. Research Gap

The literature review has defined the scope of factors that affect ULEH in rural Scotland. There are various gaps in current knowledge in which research is required to improve the design of climatically responsive ultra-low energy housing in rural Scotland.

The broad areas where knowledge is required and the primarily quantitative research will develop further understanding are:

- Illustrate the requirement for affordable rural housing with lower running costs and highlight the limitations of the existing mass market rural development models in this respect
- The continued use of the suburban development model that lacks reference to the surrounding context.
- Demonstrate the quantitative limitations in the current SAP due to the omission of regional climate data in the ZCH performance assessment methodology and therefore prove the lack of suitable building analysis research tool to rapidly and effectively measure the effects of multiple building types in multiple climatic regions in both Scotland and across the UK.
- Demonstrate the extent of the gap in SSHD performance due to reduced minimum fabric specifications (FEES), lack of MVHR and airtightness requirement in the current ZCH definition comparative to PH requirements.
- Demonstrate the requirement for more quantitative data on the effectiveness of moving towards more efficient housing forms and use of passive solar principles to lower SSHD in different regional Scottish climates.
- Lack of quantitative data to generate design guidance for producing regionally responsive ULEH in the extremes of Scottish regional climate.
- The lack of an combined method to provide mass market designs with low energy principles and qualitative design solutions for rural areas.

Previous Research in this Area

The annual Passivhaus conference presents a wealth of research in all areas of Passivhaus design (results from this research were presented in 2012 (Pearson et al. 2012)). Some issues or methods utilised in the research described below serve as a starting point. This thesis uses some of the previous research as a starting point but expands the variables and develops an alternative assessment methodology. There are a number of principle investigations that have been carried out previously that are pertinent to this study. The fabric performance specification comparison study '*International Comparison of Energy Standards in Building Regulations: Denmark, Finland, Norway, Scotland and Sweden*' was generated from recommendations in the Sullivan report to benchmark Scottish regulations and CO₂ emissions with Nordic countries due to the similar climatic weather conditions and develops a customised SAP calculation to integrate limited climate data (degree days) (Scottish Government & BRE 2009). There are many research projects which have utilised PHPP, many of which are developed for the annual Passivhaus conference. This research proposes to use a

similar ULEH glazing optimisation graph method developed by Feist and Schnieders (Passivhaus Institut & Feist 2006; Schnieders 2006) [Figure 69]. The method also used by Lundberg and Bere Architects alters the proportion of glazing in different climatic areas using PHPP to generate weather optimisation graphs for glazing areas and aims to increase thermal performance (Lundberg 2009; BERE Architects 2010b). Other developments of

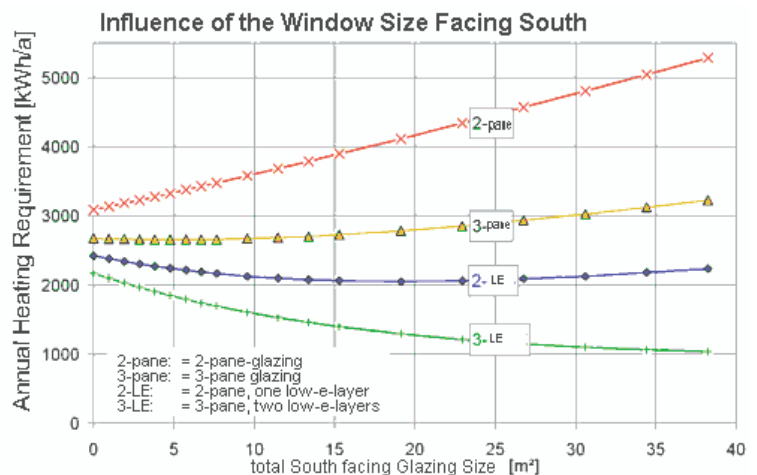


Figure 69- Weather Optimisation Graphs (Feist 2006)

PHPP involve the integration of customised results and analysis pages onto the original file. The studies within this research propose to expand the basic methodology of referencing PHPP calculation files through summary front page files developed by both Warm and Siddall (Warm 2011). It uses similar PHPP customisation techniques and calculation methods to previous research by Warm, however expands variables analysed, generates alternative data analysis techniques and develops alternative methods for control of the PHPP methodology through modification of the PHPP calculation files.

5.3. Research Aims and Objectives

This thesis will add to the quantitative knowledgebase for the design of ULEH in Scotland. The results of the thesis should also present a methodology for research in this area for further study. Thus the primary research aim is to:

- Define the design envelope for development of more contextual and qualitative approaches to ultra-low energy, rural housing in regional Scottish climates.

In order to achieve this the research will firstly demonstrate the design envelope when attempting to achieve regional solutions to ULEH in Scotland by quantifying the effects of varying key architectural parameters on the energy performance of a housing prototype across the different Scottish climatic regions. The thesis will then attempt to determine to what extent existing qualitative design exemplars can be optimised for lower space heat demands in response to the extremes of Scottish climate.

Research propositions:

- How much is the SSHD likely to increase when deviating from best practice principles across a number of variables in ultra-low energy design across rural Scotland?
- To what extent do different rural areas in Scotland require regional solutions in order to produce

ULEH?

- Are the current ZCH specifications, approaches and analysis methodologies defined in legislation suitable to reliably produce ULEH in Scotland's rural areas?
- To what extent can existing qualitative Scottish rural housing exemplar designs be used to meet ULEH standards and what changes need to be made to form, orientation and building element organisation to improve these for ULEH compliance?

The research studies are divided into two chapters; the first establishes the design envelope of ULEH in Scotland, the second analyses and optimises existing qualitative housing designs for lower SSHD and heat load.

The main aim of Chapter 6 is:

- To define the design envelope when attempting to achieve regional solutions to ULEH in Scotland by quantifying the effects of varying key architectural parameters on the energy performance of a housing prototype across the different Scottish climatic regions

In order to achieve this aim the studies in Chapter 6 ask the following questions:

- To what extent does the climatic variation across Scotland effect the SSHD of ULEH? Section 6.4 (1A)
- What are the extremes of Scottish climate in terms of SSHD performance of housing? Section 6.4 (1A)
- How do Scottish climates differ from the climate data used for UK ZCH legislation in terms of SSHD? Section 6.4 (1B)
- To what extent does the orientation effect the SSHD across the extremes of the regional Scottish climates? Section 6.5 (2A, 2B)
- What extent does roof form effect the SSHD using ULEH specification in Scotland? Section 6.5 (2C)
- To what extent does the use of an aggregated building typology reduce SSHD? Section 6.5 (2D)
- Does the inclusion of north facing glazing significantly affect the SSHD in Scotland? Section 6.5 (2E)
- Does best practice guidance for south facing guidance apply to the extremes of Scottish regional climates? Section 6.5 (2E)
- How much does the use of an MVHR unit contribute to SSHD reduction in ULEH across Scotland? Section 6.6 (3A)
- Do high levels of airtightness have a significant effect on SSHD in Scotland? Section 6.6 (3A)
- What is the impact of regional climate and the ZCH FEES specification have on SSHD in Scotland? Section 6.6 (3B)

The main aim of Chapter 7 is

- To determine to what extent do existing qualitative design exemplars can be optimised for lower SSHD in the extremes of Scottish climate.

The study in Chapter 7 asks the following questions in order to achieve the aim:

- Can a selection of existing examples of rural housing be optimised to meet ULEH SSHD?
- Do optimisations to achieve ULEH between the different regional climates across Scotland differ significantly?
- Are there different approaches to ULEH for different housing design styles across rural Scotland?
- Can optimisations to glazing areas significantly improve performance of exemplary designs?

Contribution to New Knowledge

The results of this thesis should help to influence the design and development of ultra-low energy rural Scottish housing. The definition of the design envelope for regional ultra-low energy buildings will give architects and designers a more quantitative understanding of their design decisions on the space heating energy performance of their designs. Although the primary focus of this thesis is the design of housing in rural areas, results of the research, particularly from the studies in Chapter 6 are applicable to buildings across Scotland. The clarification on the effects of regional climate and orientation on SSHD is a key contribution to new knowledge. This should enable the design of more efficient housing development layouts which can be tailored to their regional climate, whilst maximising potential reduction in SSHD. Results that demonstrate the increase or decrease in SSHD will also quantify the impact that the omission of regional climate data in the legislative analysis tool SAP will define the gap between estimated and as-built performance in ULEH across Scotland. The comparison of ZCH FEES standard and best practice in ULEH (Passivhaus) will illustrate the worst case gap in possible energy performance between ZCH and Passivhaus. This will demonstrate the implications on SSHD of the suggested use of renewables and Allowable Solutions carbon offsetting in the ZCH legislation when compared with the Passivhaus best practice, fabric first approach. The research findings will question the accuracy of current legislation and methodologies for ZCH in Scotland. The research findings will contribute to the current debate on the direction of ZCH and the implementation of the NZEB by the end of 2020 across UK.

Chapter 7 uses existing design exemplars to illustrate firstly

- how well the basic design performs in terms of ULEH
- what changes need to be made to the design to meet ULEH standard
- how these changes affect design quality

The findings of this research in Chapter 7 will add to the debate on what balance is required between contextual design and ultra-low energy principles in rural design. Ultimately the results and format of the research could be utilised and expanded to generate quantitative guidelines and advice on how best to design ULEH appropriately for various climatic areas in Scotland. This guidance could be linked to technical standards for practitioners and stakeholders similarly to PAN documentation for planning. Guidance could suggest simple best practice approaches in each climatic region in order to reduce SSHD.

5.4. Research Scope, Rationale

5.4.1. Research Scope

This research primarily focuses in the development of the knowledge base in ultra-low energy housing in rural Scotland. In this research, ultra-low energy (ULE) refers to the specific space heating demand (SSHD) rather than the overall energy use of the building. The SSHD is a significant proportion of the total energy use in housing (60%)(Department of Energy and Climate Change 2012a; Department of Energy and Climate Change et al. 2011). In terms of design the SSHD is affected by many factors including the architectural form, spatial organisations, orientation, and positioning of building elements (windows, external walls, ect). It is also affected by the fabric specification. But as this study is primarily focused on understanding how design influences ULEH an optimised fabric specification is developed to allow direct comparison of design variables.

ULEH Definition

The research uses the performance criteria based on the mainly fabric first Passivhaus principles as a benchmark to define Ultra-low Energy Housing rather than attempting to speculate on the currently undefined Scottish Section 7's Platinum Standard (ZCH) or develop an independent specification in advance of the regulatory changes. The research also uses the Passivhaus PHPP building simulation tool as a space heating performance analysis tool. This research does not suggest that the Passivhaus concept should or is fully suitable for use in UK legislation, as there is little chance for its mandatory adoption in Scotland (Scottish Government 2011e). However, the use of this approach and the PHPP analysis tool allows for an accurate measurement of space heating energy use. The research will use the fabric first approach, in addition, certain principles inherent in the Passivhaus specification will be adopted, namely: the use of a high specification building envelope and MVHR. Passivhaus concept coupled with the PHPP simulation methodology is the leading proven concept for the design and assessment ULEH and has been proven across thousands of properties in Europe (Schnieders 2003). The Passivhaus concepts criteria for Heat Load and SSHD criteria simplify the energy consumption so it is independent of heating systems and fuels in comparison to the UK carbon compliance figures. This approach suits the studies focus on the analysis and development of more energy efficient forms of housing through alterations to the fabric design as the calculations are based on SSHD heat losses and heat gains rather than CO₂ emissions.

Areas within Research Scope

[Figure 70]

The research primarily explores the quantitative effect of building form on space heating energy use of housing in different climatic areas across Scotland. The research concentrates on rural areas, as there is a requirement for more appropriate lower energy housing due to population increases and the requirement for more contextually responsive housing. Additionally there is a requirement for more affordable housing with low running costs due to expensive fuels and increased heating requirements. The research focuses primarily on housing design, orientation and performance rather than developing specific site planning

layouts. However further development of results from this research could be used to determine more suitable site specific planning layouts. Various formal variations are studied in detail across the extreme regions of the Scottish climate. The research concentrates on quantitative design issues rather than suggesting new qualitative models for appropriate rural design but will discuss the qualitative implications on housing designs. The research aims to create knowledge for general guidance on the effects of climate variation and building form in Scotland. The final study explores the optimisation of existing qualitative models for use as ULEH in terms of SSHD or heat load in the extremes of Scottish climate.

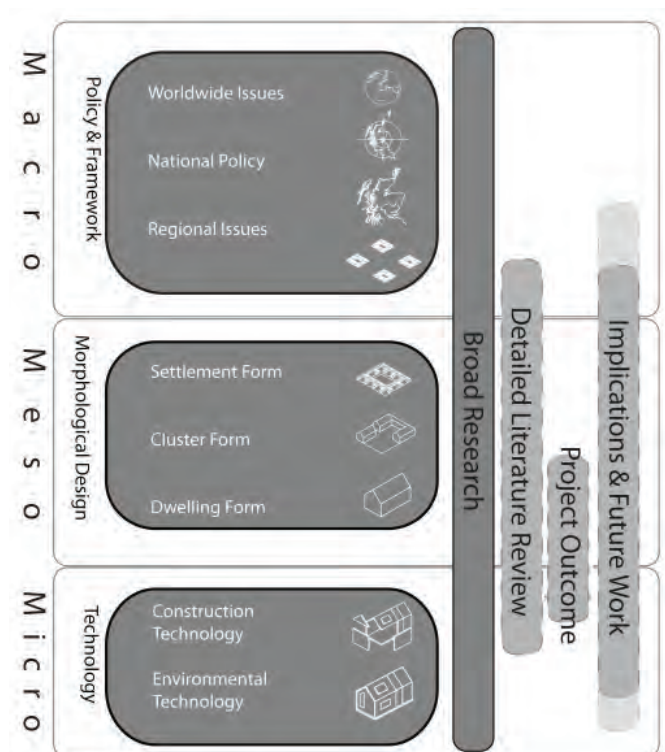


Figure 70- Research Boundaries

Areas not within Research Scope

The research does not aim to develop new housing development layouts or models and does not develop technical systems or costing models. Additionally the research does not aim to define a position on appropriate, qualitative architectural contextual design or a position on the relevance of critical regionalism in Scotland. The study develops a series of typical elemental u-value specifications suitable for Passivhaus in the UK. The effects of variations of building fabric such as specific wall build-ups, window types, and lightweight\ heavyweight constructions are not explored in this study. The study does not consider cost implications of altering building materials, services or changes to building envelope. This study does not intend to prove or disprove the cost effectiveness of Passivhaus or other ULEH approaches in the Scottish context. Passivhaus and ULEH is currently an emerging market; therefore, there are large variations in current cost estimates and final construction costs from built development across Scotland. There are also a considerable number of Whole Life Costing and viability studies from both the UK and Europe on this topic. The study does not aim to generate a range of one off house types that are specific to one site or climatic region in Scotland as this method is deemed as too subjective for this research.

This study does not aim to suggest methods for improving existing buildings, as there are various government incentives regarding this. As this research is exploring the topic from an architectural background, looking towards new houses is a more suitable topic as the building form and positioning have a significant effect on space heat demand.

5.4.2. Research Rationale

The Viability in the Use of Fabric First Approach in Rural Areas

The research suggests the use of a fabric first approach to achieving ULEH. The tried and tested ULEH fabric first concept- Passivhaus aims to reduce space heating energy consumption as far as reasonably possible in new houses through a very high specification thermal envelope and MHVR unit. Use of this concept significantly reduces space heating energy, which represents around 60% of the total energy use in housing (Department of Energy and Climate Change et al. 2011). The implementation of more efficient housing plan layouts that use fabric first principles which take greater advantage of solar gains and reducing heat losses would contribute to lowering the space heating energy use of housing. The use of ULEH approach could be more beneficial in rural areas than in urban areas due to a number of reasons including the increased requirement for low running cost housing, more expensive fuels, reduced grid connection to low cost fuels and harsher climatic conditions. ULEH also requires less infrastructural connections such as grid connections for energy generating technologies and alternative fuel sources for space heating (oil or gas).

Main Research Variables

Many variables have an effect on the space heating energy performance of a house. Three main areas are; climatic, formal and technical. These areas have different drivers; site, context, brief and legislation. Key variables from these areas will be explored in the research projects.

Climatic Variation

The climatic variation across Scotland is significant with large regional temperature and solar insolation difference having a significant effect on the performance of an ultra-low energy house. A building simulation study using PHPP to determine the effects of climatic variation and orientation on space heating energy performance is required. This involves the development of a best practice ultra-low energy prototype (6.4) to be used as a vehicle to analyse different climatic regions across a range of orientations in section 6.5 (2A, 2B). The study in section 6.4 (1A, 1B) determines the variation of space heat demand due to regional variation.

Formal Variation

The building form is known to have a significant effect on the energy performance of buildings. Variation from generic low energy best practice guidelines causes lower performance but there is no quantifiable information on the implications when deviating from this in Scotland. The research studies in section 6.5 (2C, 2D, 2E) illustrate the design flexibility when developing ultra-low energy housing by comparing the effect of various architectural design variables. Studies in Chapter 7 determine the variation of SSHD and heat load due to the formal variation of existing rural designs.

Technical Variation

The minimum technical specification has a significant impact on the thermal performance of buildings. The use of high levels of airtightness and MVHR is required in some ULEH approaches and reduces heat losses

through unwanted and required ventilation. The study in section 6.1 (3A) analyses the effect of varying air tightness levels and effect of mechanical ventilation heat recovery (MVHR) on heating demand. The definitions of technical standards in the UK's ZCH legislation differs significantly from that of Passivhaus and other ULEH approaches. The study in 6.1 (3B) examines the effect specifications have on the energy requirement of the prototype. These studies use the previous methodology, PHPP and the best practice building prototype to assess the effectiveness of high levels of airtightness and the use of a MVHR unit in the Scottish climate.

5.5. Research Structure

This research will investigate whether an appropriate and sustainable approach to develop more nuanced housing is to use fabric first design principles to design ULEH. The proposition is whether in making the building form more efficient rather than the use of renewable technology or offsetting to compensate for extra building emissions/energy use resulting from an inefficient building form or lower thermal specification as proposed UK ZCH legislation suggests. The research proposes that strategies for ultra-low energy housing should be developed at a regional level from the design stage using passive solar principles where possible. It is necessary to consider strategies at a regional scale due to the significant climatic variation across Scotland, rather than at a national level as current legislation enforces (St. Andrew's House Scottish Government 2011c). The current knowledge, guidance and legislative gap between design and technical performance suggests that there is an opportunity to improve buildings space heating energy efficiency by implementing regional design tailored to their context using sensitive ultra-low energy housing assessment tools. Currently the knowledge does not exist to develop this guidance.

5.5.1. Use of Passive House Planning Package Rationale (PHPP)

The simulation tool PHPPs primary purpose is for the design and certification of ULEH (Passivhaus). It is widely recognised as a very effective and accurate design tool with transparent calculation methods and regional climate data making PHPP suitable to design and simulate more context and climate specific approaches to ultra-low energy housing. The detailed numeric data input methodology makes PHPP an effective tool for use in this research study due to the ability to rapidly alter the prototype's dimensions and component specifications can alter with simple numeric input rather than the alteration of a complex three dimensional cad model. As the PHPP uses an unprotected Excel the workflow is extremely flexible allowing inputs, outputs and calculations to be directly referenced or linked to another sheet within the same file or to a customised Excel sheet or Excel file. Therefore, it is possible to develop customised input and output sheets and simplify data entry and analysis for each specific study and follows a similar approach to that of Warm and Siddall's PHPP output summary front pages (Warm 2011). All of the results rely on simple formulae discussed within the Passivhaus designer course which are illustrated in the same format in PHPP (Intelligent Energy Europe 2011). The main results from the PHPP can be traced back to the heat gains and losses and through calculations to the individual elemental performance. It is possible to extract data

anywhere through the calculations. The calculation process facilitates simple alterations to the model once it has been established, and displays results instantaneously. It is possible to monitor the effects of design and technical changes with ease across different result areas due to the multi-window Excel platform. The proven accuracy of generated output due to the flexibility, and continuous development through post occupancy testing prove the PHPP to be one of the most accurate whole house thermal simulation tools available.

The study proposes to use PHPP for building simulation modelling. This methodology is used due to its:

- Development as a tool specifically for the design and certification of ultra-low energy buildings
- Ability for customisation using Excel
- Transparent calculation methodology with working displayed as simple calculations
- Proven accuracy and sensitivity to minor changes to technical specification.

Although PHPP data entry is complex, the proposed research studies are comparative and the variables for the data will be predominantly limited to the building metrics, climate data and adjustment of the building fabric. Therefore once the original template is established the data entry steps require relatively simple inputs. The few inputs that are required can be simplified using referencing features within Excel. This initial advanced requirement for data entry means that PHPP also has the ability to be more accurate with entry of more specific inputs possible.

5.5.2. Research Outline

[Figure 71]

The two main research projects described in the following two chapters are quantitative analysis projects using PHPP. The first series of studies defines the *Quantitative Analysis of Building Form and Positioning on SSHD of ULEH in Scotland (Chapter 6)* and has been developed to test the extent of the variation in SSHD across a number of variables. The second series of studies is discussed in Chapter 7 titled: *Passive Solar Analysis and Optimisation of Qualitative Scottish Exemplary Designs*, and analyses a number of exemplary house designs in terms of ULEH performance and then goes on to investigate what design modifications are required to improve these for ULEH compliance.

The initial stage in this first project generates a ULEH (Passivhaus) compliant 107m² *Doll's house prototypes*. The *Doll's house* is a method used in the Passivhaus designers' course that aims to design a simple, best practice-housing layout. This prototype defines the thermal specification required for best practice in a range of Scottish regions. Further details regarding the design and specification of the prototype are in section 6.4.1. A customised version of PHPP is developed for the research projects. PHPP's primary use is as a certification tool for single houses in one climatic region, it's methodology is not designed for multiple climate data's and significant alterations to building design. This is discussed in section 6.1.1. The prototype is used to test the effect of a range of formal and locational variables on the SSHD in Scotland. These variables include climatic region, orientation, and roof form, glazing areas, typology and technical specification. Results of these studies can be found in sections 6.4- 6.6. The findings and customised methodology from this study define a basis for the following project described in Chapter 7. This second

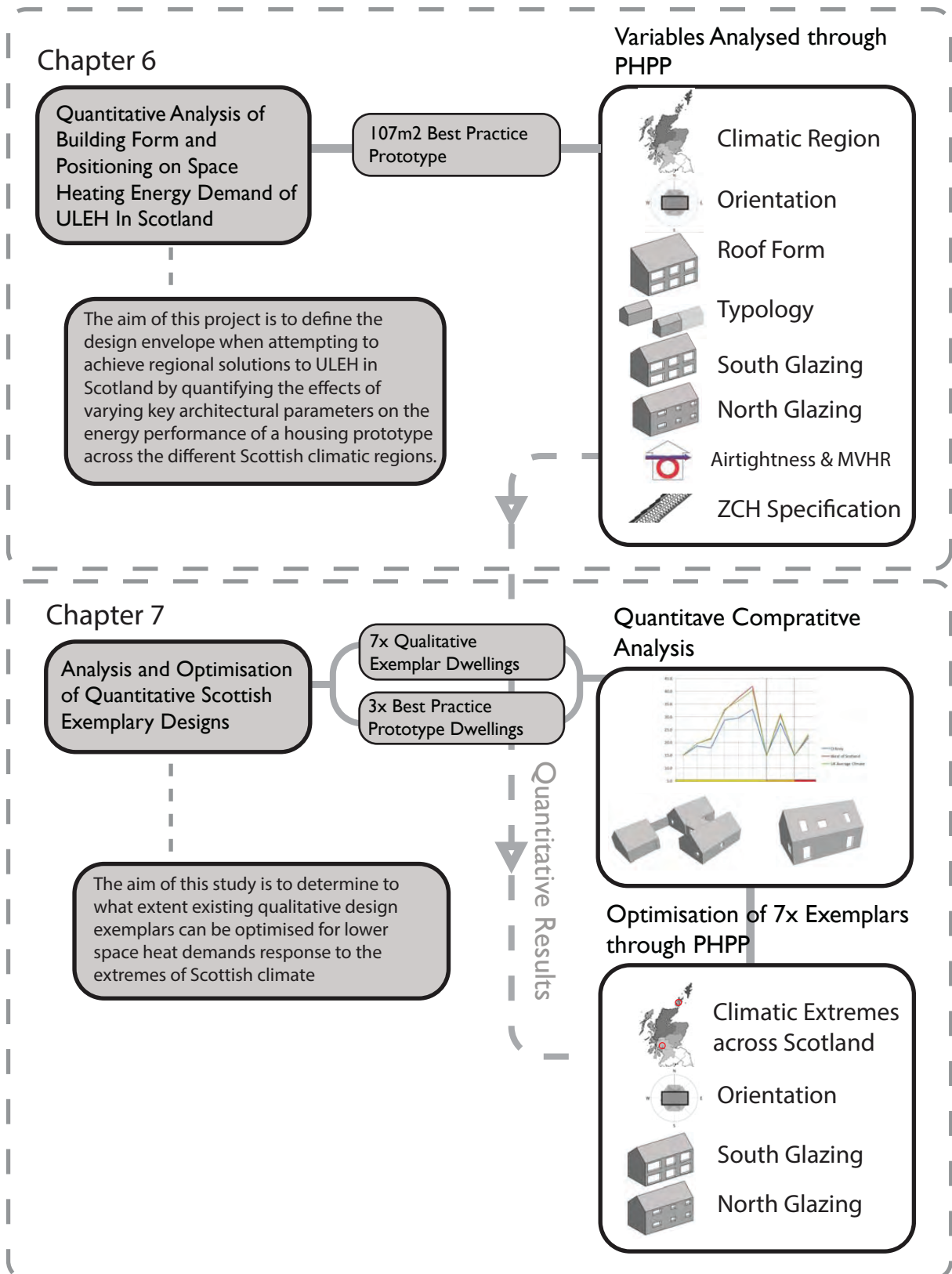


Figure 71- Research Studies Outline

project selects and analyses three control prototypes and seven qualitative exemplary rural designs for SSHD in the extremes of Scottish Climate. The exemplary designs were selected from the Scottish Government's Inspirational Designs database and best practice initiatives, discussed in section 7.2. The orientation and window areas of the seven exemplars are then optimised for SSHD in the extremes of the Scottish climate to produce more efficient designs that respond to context and climate.

5.6. Development of a Custom PHPP Methodology

Early studies and a working knowledge of PHPP demonstrated the requirement for a customised PHPP methodology due to the onerous data input requirements and complexity of workflow. [Figure 72] Illustrates the sequence of inputs from the PHPP manual (Passivhaus Institut 2007, p.30). The PHPP is primarily used as a building design and certification tool for the design and optimisation of single Passivhaus dwellings. The input methodology does not work efficiently when making significant changes to building metrics as inputs are spread over multiple sheets. To enter in a simple building design it requires data entry across many different excel sheets with complicated layouts. This makes copying and pasting of data impossible. The intricacy of this research study and its utilisation of several building forms across multiple climate data regions and the inherent complexity of detailed data input in PHPP prompted the design of a customised interface. The PHPP software is built on an unprotected Microsoft Excel Spread sheet and is therefore customisable. Changes made to the original PHPP methodology can be broken down into three areas; Climate, Input and Output. The majority of the 30 sheets within the PHPP calculation file are used to both input and output detailed data and calculation workings.

The customised version uses simplified input and output processes that only require selected data entry to produce results. The input cells are linked from the master document to the different PHPP calculation files. Selected results of the PHPP calculation files are linked back to the Master file to compile results. To enable multiple climates to be analysed simultaneously each of the climatic regional data sets have their own PHPP calculation file with general values entered for the majority of the data input fields which remain consistent for all studies. [Figure 73] illustrates a simple schematic of the linkages between Master Input and Output file and the PHPP Excel calculation files. The fields with variable data input link to a new Master Excel File containing the simplified input sheets. Therefore, when the Master file is altered all of the linked PHPP calculation files will update to match the Master file.

The first version of the customised file allowed for all of data inputs to be entered on a single sheet with an area to store previously entered data. Later versions referenced data entries from another sheet. Summaries such as totals and percentages of output data are displayed next to the input data, and are continuously updated when input values are changed. [Figure 74] shows the input section to the left and summaries of results on the right described and shown in more detail in *Side by Side Climate and Thermal Analysis Results Table* below. This has the added advantage of clearly highlighting errors or discrepancies in the data input. The results of each of the PHPP climate calculation files are compiled into tables and graphs within the customised file.

Several limitations were found through the process of the research. Any PHPP inputs that are not linked to

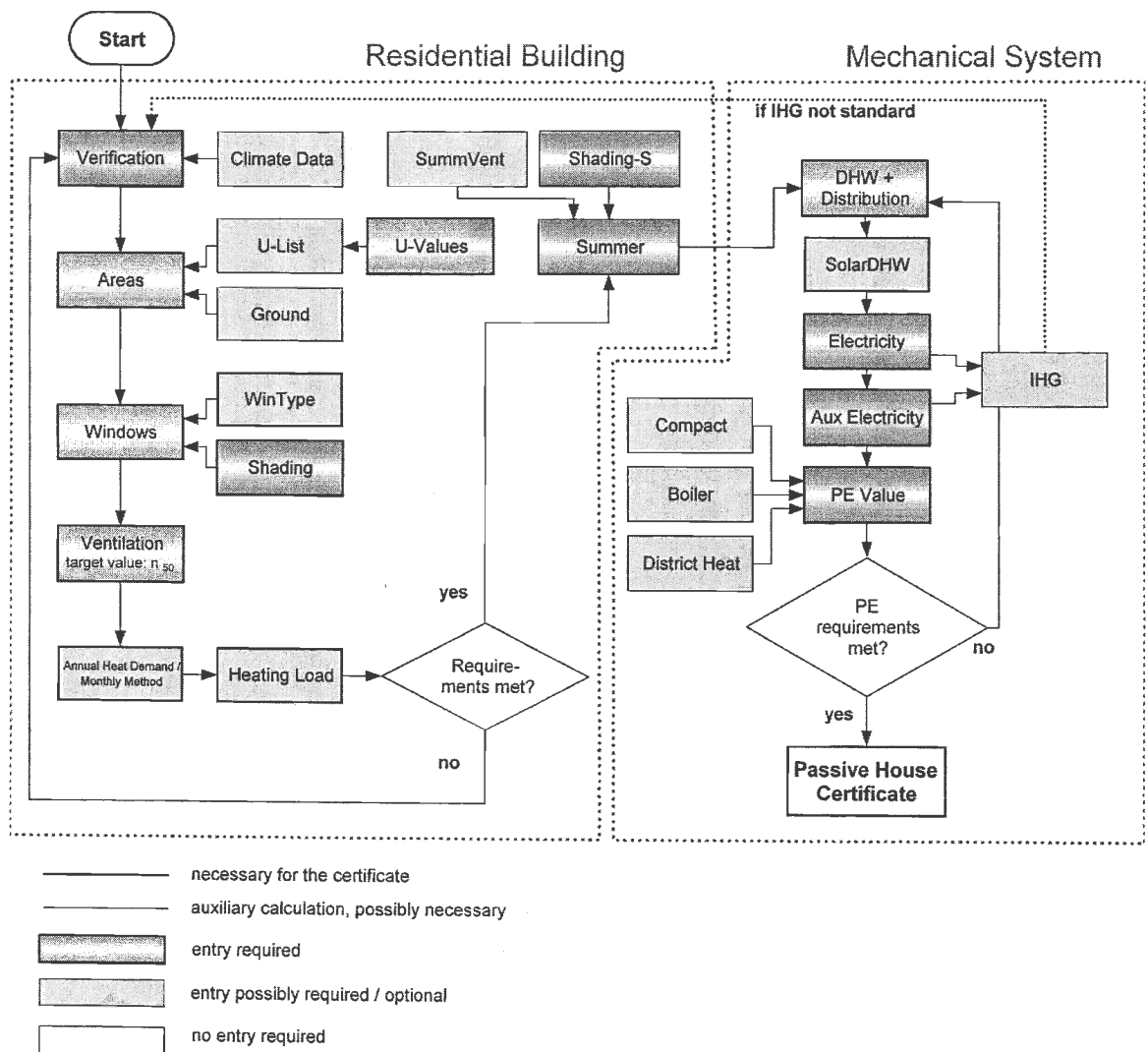


Figure 72- PHPP Calculation Methodology

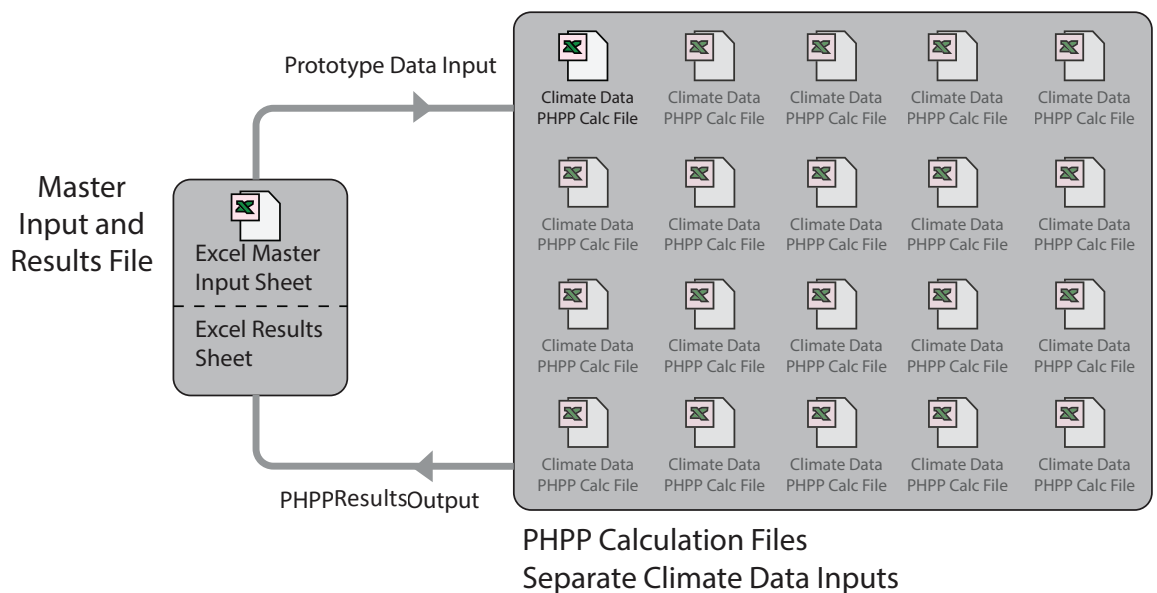


Figure 73- Schematic of linkages between input and output and the PHPP calculation files

Inputs

Results

Inputs		Title of Study		UK Average Climate								
Areas	Floor	107	(8 Norm 16 Part)	Specific Space Heat Demand,	13.9							
	North Wall	61.36	8	Orkney 20								
	South Wall	61.36	8	Specific Space Heat Demand,	22.1							
	East Wall	43.05	8	West Scotland 15								
	West Wall	43.05	8 Per	Specific Space Heat Demand,	12.7							
	Floor Slab	69.6	35	East Scotland 16								
	Roof	89.7		Specific Space Heat Demand,	13.4							
	Parti Wall Roof WEST	0										
	Parti Wall Roof EAST	0										
Windows	North Windows	1	1.9	2	1	North=1	0	3.8				
	East Windows	2		0	3	East=3	90	0	6.19%			
	31% South Windows	2	1.25	1.9	8	South=2	180	19				
	19% West Windows	2	1.2	1.9	5	2	180	11.4	49.54%			
	Horizontal Windows	2		0	4	West=4	270	0				
	Door	2		0	4	270	0	0.00%				
					6	Roof=6	0	0				
		1.1	2.25					0	Deviation from South	0.00%		
						Watch for Parti Area						
						East x Length	507.99	Watch for Parti Area				
Volumes	Enclosed (Gross Volume)	507.99				Length	11.8	Done				
	Ventilation Volume											
Occupants	Occupants	4										
Ventilation	Summer Ventilation											
	Air Change by Natural	1.49										
	Night Ventilation	1.49										
	Mechanical	0.3										
U-Values	Walls	Thickness	0.117	34.1								
	Roof	0.117	34.1									
	Ground	0.181	27.6									
	Glazing	g-Value	0.52	0.61								
	Frame	Y-Spacer	0.043	0.63	0.04							
		U-Value	0.52	0.61								
		Y-Installation	0.043	0.63	0.04							
		Inputs for South Facing 15 kWh/m2a										
		Orkney	West	East								
		0.092	0.158	0.151								
Ground	Joest House Temp	Insulation W/D	0.71									
	Thickness	0.1										
	Thermal Conductivity	0.02	W/(mK)									
Shading	Reveal Depth	South	0.2	0.2	0.2	0.1						
	Glaze to Reveal	East+West	0.05	0.05	0.05	0.195						
	Overhang	North	0.2	0.2	0.2	0.15						
	Glaze to Overhang	Horizontal	0.05	0.05	0.05	0.05						
	Add	100%	100%	100%	100%							
	Summer Shading (0 total)	50%										
Heat Demand and Load	SSHD (Annual)	14.9	21.0	11.5	12.7	14.5	16.0	18.9	20.5	20.6	12.8	kWh/(m2a)
	SSHD (Monthly)	15.7	21.6	12.8	13.5	15.7	17.1	21.0	22.2	21.9	13.6	kWh/(m2a)
	Heat Load	12.2	14.9	10.0	10.7	12.4	14.6	14.1	12.2	14.5	11.2	(w/m2)
	Overheating	0	0	0	0	0	0	0	0	0	0	%
Heat Gains	Total Solar Heat Av	62.5	63.8	66.8	74.7	70.6	69.6	61.1	58.2	64.8	65.8	kWh/(m2a)
	Solar Heat Gain Upl	40.8	46.8	42.1	47.4	46.7	47.4	40.4	41.6	46.9	42.6	kWh/(m2a)
	Internal Heat Gain	12	13	12	12	12	13	12	13	13	12	kWh/(m2a)
	Solar Utilisation Fac	65%	73%	63%	64%	66%	68%	66%	72%	72%	65%	kWh/m2a
	Heat Gain Total	52.8	60.2	53.7	59.1	58.9	59.9	52.6	54.8	60.2	54.5	kWh/(m2a)
Heat Losses	Heat Loss Windows	24	29	23	25	26	29	26	27	29	25	kWh/(m2a)
	Heat Loss Walls	21	25	20	22	23	21	22	23	25	18	kWh/(m2a)
	Heat Loss Ground	6	8	6	7	7	9	7	7	8	6	kWh/(m2a)
	Heat Loss Roof	11	13	10	11	12	11	11	12	13	9	kWh/(m2a)
	Heat Loss Door	2	2	2	2	2	2	2	2	2	2	kWh/(m2a)
	Heat Loss Ventilatic	5	6	5	6	6	6	6	6	6	6	kWh/(m2a)
	Heat Loss Total	68.6	81.9	66.5	72.6	74.6	77.0	73.6	77.0	82.2	68.1	kWh/(m2a)
Windows	North Windows	-22	-85	-13	-32	-43	-76	-50	-78	-88	-41	
	East Windows	0	0	0	0	0	0	0	0	0	0	
	South Windows	4146	3856	4677	5312	4808	4468	3836	3432	3952	4374	
	West Windows	0	0	0	0	0	0	0	0	0	0	
	Horizontal Windows	0	0	0	0	0	0	0	0	0	0	
	Energy Balance for	4124	3773	4664	5280	4765	4392	3786	3354	3863	4333	
	Energy Balance /m2	39	35	44	49	45	41	35	31	36	40	
House Type Metrics	% HL	Area m2	Area %									
	Heat Loss Windows	35%	34	9%								
	Heat Loss Walls	30%	175	47%								
	Heat Loss Ground	9%	70	19%								
	Heat Loss Roof	16%	90	24%								
	Heat Loss Door	2%	2	1%								
	Heat Loss Ventilatic	8%										
Areas	Floor Area m2	107.00	m2									
	Volume m3	507.99	m3									
	Volume (Ventilation) m3	258	m3									
	Area/ Volume Ratio (Gross)	0.73	m2/m3									
	Exposed Surface Area m2	371	m2									
	Glazing Area (Glass) m2	34.2	m2									
	Effective Due South Glazing	30.40	m2									
J-Values	Walls	0.14	W/(m2K)									
	Window	0.8261	W/(m2K)									

Figure 74- Customised Input and Results Summary Masterfile

the master file require alteration in each of the climate data PHPP files. All PHPP climate data calculation files must be opened simultaneously with the master file otherwise results will not be updated. However using a standard computer there was virtually no delay to run studies. The number of linkages throughout both the climate data calculation PHPP file and the master file require in-depth testing to ensure accuracy and correct connections.

5.6.1. Initial Custom Data Input Sheet

[Figure 75]

The PHPP software has a number of usability problems due to its complexity of data input. Simple data inputs are spread across multiple sheets, using linked cells, a customised data input sheet has been developed. This allows rapid input of commonly changed data. The page contains formulae to feedback information such as totals and percentages as data is being entered. Using this custom sheet errors or discrepancies can be quickly noted and rectified. Each of the climate data inputs has a separate Excel file. The fixed variables are already entered into each of the files. Each of these files references the master input sheet for the variable data below, allowing variables to be controlled from the single master input cells.

Main Input Categories

Areas

- Floor Area
- Wall Areas
- Floor Slab Area & Perimeter
- Party Wall Area

Windows

- Rough window opening dimensions
- Number of Windows
- Orientation of Windows
- Door Size
- Outputs Wall area and % of window/ wall

Volumes

- Enclosed Volume
- Ventilation Volume

Occupants

- Number of Occupants

Summer (Ventilation)

- Natural Ventilation Rate
- Night Ventilation Rate
- Summer Mechanical Ventilation Rate

U-Value and thicknesses

- Wall
- Roof
- Ground

Windows

- Glazing- G-Value, U- Value
- Frame- Y- Space, Y Installation, U-Value

Ground Perimeter Insulation

- Insulation Width
- Thickness
- Thermal Conductivity

Shading (All windows)

- Reveal Depth
- Glazing to Reveal
- Overhang
- Glazing to Overhang
- Additional Shading Factor

Inputs Areas

Title of Study

Floor
North Wall
South Wall
East Wall
West Wall
Floor Slab
Roof
Parti Wall Roof WEST
Parti Wall Roof EAST

	107	
	61.36	8
	61.36	8
	43.05	8
	43.05	8
	69.6	35.2
	89.7	
	0	
	0	

UK Average Climate

Specific Space Heat Demand, 13.605

Orkney 20

Specific Space Heat Demand, 22.171

West Scotland 15

Specific Space Heat Demand, 12.760

East Scotland 16

Specific Space Heat Demand, 13.496

Windows

	Width	Height	No	Dev Nrth	Area	Area	% Area of Surface
North Windows	1	1.9	2	1	North=1	0	3.8
			0	1		0	6.19%
East Windows			0	3	East=3	90	0
			0	3		90	0.00%
31% South Windows	1.25	1.9	8	2	South=2	180	19
19%	1.2	1.9	5	2		180	11.4
							49.54%
1.67 West Windows			0	4	West=4	270	0
			0	4		270	0.00%
Horizontal Windows			0	6	Roof=6	0	0
Door	1.1	2.25				0	0.00%

Watch for Parti Area

Volumes

Enclosed (Gross Volume)
Ventilation Volume

507.99

East x Length
Length

507.99
11.8

Watch for Parti Area
Done

Occupants

Occupants

4

0.14
0.14
0.15

Ventilation

Summer Ventilation

Air Change by Natural
Night Ventilation
Mechanical

1.49
1.49
0.3

U-Values

Walls
Roof
Ground

Thickness	
0.117	34.1
0.117	34.1
0.181	27.6

Glazing

g-Value	Ug- Value
0.52	0.61

Frame

Y-Spacer	Uf- Value	Y Installation
0.043	0.63	0.04

Original Inputs

0.117	34.1	
0.117	34.1	
0.181	27.6	
g-Value	Ug- Value	
0.52	0.61	
Y-Spacer	Uf- Value	Y Installation
0.043	0.63	0.04

Inputs for South Facing 15 kWh/(m2a)

Orkney	West	East
0.092	0.158	0.151

Ground

Joes House Temp

Insulation W/D

0.71

Thickness

0.1

Thermal Conductivity

0.02

W/(mk)

Input for Ventilation Climate 16

PH CSH

0.6 Ach 1.3 Ach

0.14 w/m2 0.14 w/m2

Shading

Reveal Depth
Glaze to Reveal
Overhang
Glaze to Overhanh
Add
Summer Shading (0 total)

South	East+West	North	Horizontal
0.2	0.2	0.2	0.1
0.05	0.05	0.05	0.195
0.2	0.2	0.2	0.15
0.05	0.05	0.05	0.05
100%	100%	100%	100%
50%			

Figure 75- Customised Input Sheet used in Chapter 6

- Summer Shading (South only)

5.6.2. Custom PHPP Results

The custom results pages were developed to integrate results from multiple calculation files to allow detailed analysis and comparison of PHPP data output. Various sheets were developed throughout the research studies. The prototype design results page is located within the PHPP calculation file.

5.6.2.1. Full Results Page

This section of the results page is a summary of the physical properties of the particular prototype. Some values are reference from PHPP, others are generated by a PHPP data and additional formulae (Loss %, Surface to Volume Ratio, etc). This results page is within each of the PHPP calculation files that contain climatic information and the PHPP calculation workings. All of the results are live and will alter with alterations to the building design.

[Figure 76]

Heat loss percentage through:

- Windows
- Walls
- Ground
- Roof
- Door
- Ventilation

Surface Area and percentage of exposed surface area of:

- Windows
- Walls
- Ground
- Roof
- Door

Areas and Volumes

- Floor Area
- Volume/Ventilation Volume
- Area/Volume Ratio
- Exposed Surface Area
- South Glazing Area/Percentage of South Wall
- Percentage of Glazing to Exposed Envelope

U- Values

- Walls
- Window Average



- Ground
- Prototype Average

5.6.2.2. Simplified Single Climate Results Table

This results page gives a simplified version of the *Full Results Page*. This table displays the main data associated with the performance of the building for a single climate. There is a separate Results table for each climate in the same sheet.

Climate

This section shows a summary of the factors that have an effect on the thermal analysis studies. The solar insolation total and Gt value (Heating Degree Hours) are included.

Heat Gains

Data such as the utilisation factor can illustrate how efficiently the building is working with heat gains in the climate.

Heat Losses

This part of the spread sheet details all of the heat losses from the building, and breaks this down into areas and percentages; this aids the comparison between different designs.

Windows

Data regarding the energy balance of the windows allows the user to identify the overall effect of the window for each elevation.

5.6.2.3. Side by Side Climate and Thermal Analysis Results Table

[Figure 77]

This summary section displays a simplified version of the *Simplified Single Climate Results Table* alongside the data inputs. It allows a comparison between the climatic regions the particular design.

5.6.3. Custom Input and Output Sheet Development

After the initial development of the customised PHPP master file through the studies discussed in Chapter 6 a series of improvements were made.

5.6.3.1. Data Entry Improvement

The main improvements increased the data entry fields for glazing due to more complex housing designs, new and the data entry process was altered. The data entry for the building types required updating due to the complexity and variation between the designs in Chapter 7. The previous method which involved cutting and pasting across one sheet was no longer suitable. A method was developed to reference a separate design input sheet which essentially contained a data base of the relevant input data for each house type.

Region	NW Eng	Borders	West Scotlan	East Scotlan	North Eas	Highla	Wester	Orkney 20	Shetla	UK Average	Climate
Latitude	54.88	55.317	56.467	56.45	57.167	57.2	58.22	58.95	60.1	51.893048	
Longitude	-2.93	-3.2	-5.433	-3.067	-2.083	-3.83	-6.317	-2.9	-1.2	-2.219667	
Gt (Heating Degree	66	77	61	69	70	77	66	69	72	69	
Solar Isolation Total	954	957	946	1077	1021	1007	791	775	821	1004	

Heat Demand and Load

SSHD (Annual)	14.9	21.0	11.5	12.7	14.5	16.0	18.9	20.5	20.6	12.8	kWh/(m2a)
SSHD (Monthly)	15.7	21.6	12.8	13.5	15.7	17.1	21.0	22.2	21.9	13.6	kWh/(m2a)
Heat Load	12.2	14.9	10.0	10.7	12.4	14.6	14.1	12.2	14.5	11.2	(w/m2)
Overheating	0	0	0	0	0	0	0	0	0	0	%

Heat Gains

Total Solar Heat Av	62.5	63.8	66.8	74.7	70.6	69.6	61.1	58.2	64.8	65.8	kWh/(m2a)
Solar Heat Gain Util	40.8	46.8	42.1	47.4	46.7	47.4	40.4	41.6	46.9	42.6	kWh/(m2a)
Internal Heat Gain	12	13	12	12	12	13	12	13	13	12	kWh/(m2a)
Solar Utilitisation Fa	65%	73%	63%	64%	66%	68%	66%	72%	72%	65%	kWh/a

Heat Gain Total	52.8	60.2	53.7	59.1	58.9	59.9	52.6	54.8	60.2	54.5	kWh/(m2a)
-----------------	------	------	------	------	------	------	------	------	------	------	-----------

Heat Losses

Heat Loss Windows	24	29	23	25	26	29	26	27	29	25	kWh/(m2a)
Heat Loss Walls	21	25	20	22	23	21	22	23	25	18	kWh/(m2a)
Heat Loss Ground	6	8	6	7	7	9	7	7	8	8	kWh/(m2a)
Heat Loss Roof	11	13	10	11	12	11	11	12	13	9	kWh/(m2a)
Heat Loss Door	2	2	2	2	2	2	2	2	2	2	kWh/(m2a)
Heat Loss Ventilatio	5	6	5	6	6	6	6	6	6	6	kWh/(m2a)

Heat Loss Total	68.6	81.9	66.5	72.6	74.6	77.0	73.6	77.0	82.2	68.1	kWh/(m2a)
-----------------	------	------	------	------	------	------	------	------	------	------	-----------

Windows

North Windows	-22	-85	-13	-32	-43	-76	-50	-78	-88	-41
East Windows	0	0	0	0	0	0	0	0	0	0
South Windows	4146	3858	4677	5312	4808	4468	3836	3432	3952	4374
West Windows	0	0	0	0	0	0	0	0	0	0
Horizontal Windows	0	0	0	0	0	0	0	0	0	0

Energy Balance for	4124	3773	4664	5280	4765	4392	3786	3354	3863	4333
--------------------	------	------	------	------	------	------	------	------	------	------

Energy Balance /m2	39	35	44	49	45	41	35	31	36	40
--------------------	----	----	----	----	----	----	----	----	----	----

House Type Metrics

% HL Area m2 Area %

	total surface area		
Heat Loss Windows	35%	34	9%
Heat Loss Walls	30%	175	47%
Heat Loss Ground	9%	70	19%
Heat Loss Roof	16%	90	24%
Heat Loss Door	2%	2	1%
Heat Loss Ventilatio	8%		

ratio loss to area????

Areas

Floor Area m2	107.00	m2
Volume m3	507.99	m3
Volume (Ventilation) m3	268	m3
Area/ Volume Ratio (Gross)	0.73	m2/m3
Exposed Surface Area m2	371	m2
Glazing Area (Glass) m2	34.2	m2
Effective Due South Glazing	30.40	m2
	9%	Glass/Surface
	50%	Glass/Main Facade (Check Input)

U-Values

Walls	0.14	W/(m2K)
Window	0.8261	W/(m2K)

Figure 77- Side by Side Climate and Thermal Analysis Results Table

The house types were selectable from a pull down menu. [Figure 78] A similar data input method was developed for the alteration to the building orientation where the deviation from north is selectable from a pull down list. Additionally inputs for the U-Value specification were also selectable through pull down menus. These improvements are discussed in more detail in section 7.1.1.

5.6.3.2. Detailed Building Analysis Results Page

[Figure 79]

The culmination of the research studies in Chapter 7 resulted in the generation of another detailed summary analysis table that could be easily entered into a table for comparison with other designs. This table contains the similar information from the *Full Results Page* illustrated in figure 76 but reformatted to a simpler vertical format. The upper half of the Excel sheet contains detailed building metrics which remain almost constant across climatic areas and the lower half is the format of climate specific information. The image only illustrates one table of climatic information for Orkney.

Scotframe Clousta SSDH									
(8 Norm 18 party)									
Floor	102.94								
North Wall	44.05	8.00							
South Wall	52.02	8.00							
East Wall	35.36	8.00							
West Wall	35.33	8.00	Perimeter						
Floor Slab	128.74		57.24						
Roof	182.29								
party Wall Roof WEST									
party Wall Roof EAST									
House Study Input									
	Width	Height	No	Dev	Nrth	Area			
North Windows	0.75	1.05	2	1	North=1				
	2	0.95	1.05	1	1				
	3	0.9	1.05	2	1				
	4	0	0	0	1				
East Windows	0.75	1.05	2	3	East=3				
						90			1.575

Scotframe Clousta SSDH

Rural Design R2 Relaxed ORKNEY

Scotframe Clousta SSDH

improved OHebr EAST SSDH

IMP OHebr South SSDH

IMP WOS OHebr South SSDH

imp WOSNORD Single House

Imp NORD End Terrace/Semi

imp ORK NORD Single House

Figure 78- Custom PHPP Data Input Pull Down Menu

5.6.3.3. Final Master File Workflow

[Figure 80] illustrates the finalised customised Master file workflow and demonstrates the linkages between the Master file and calculation files. The Master file also holds all of the previous results from the studies. Separate sheets hold the summaries of all building types and the associated graphs found in the research. This allows for the checking of previous results and associated building metrics.. This is the final developed version master file workflow and was used in Chapter 7 for all studies.

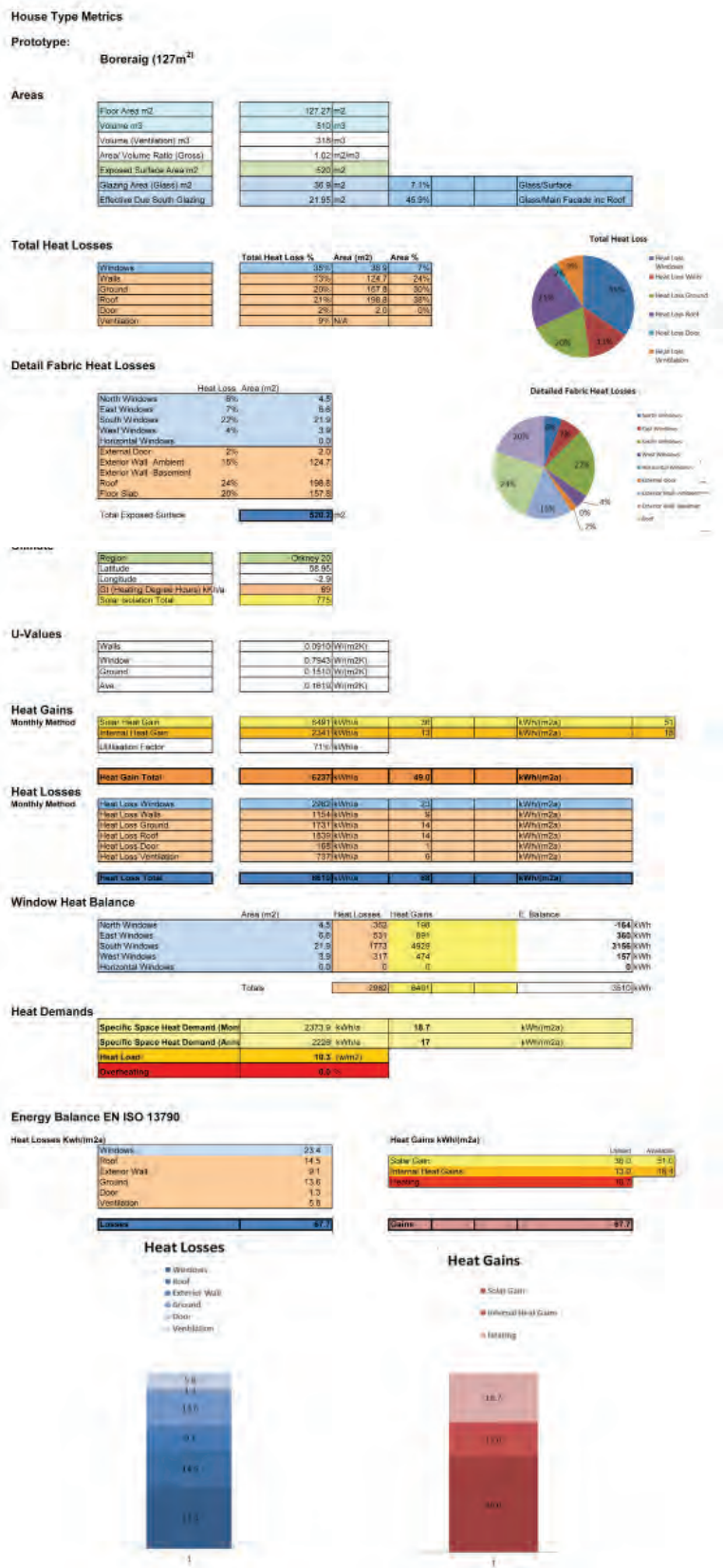


Figure 79- Detailed Building Analysis Results

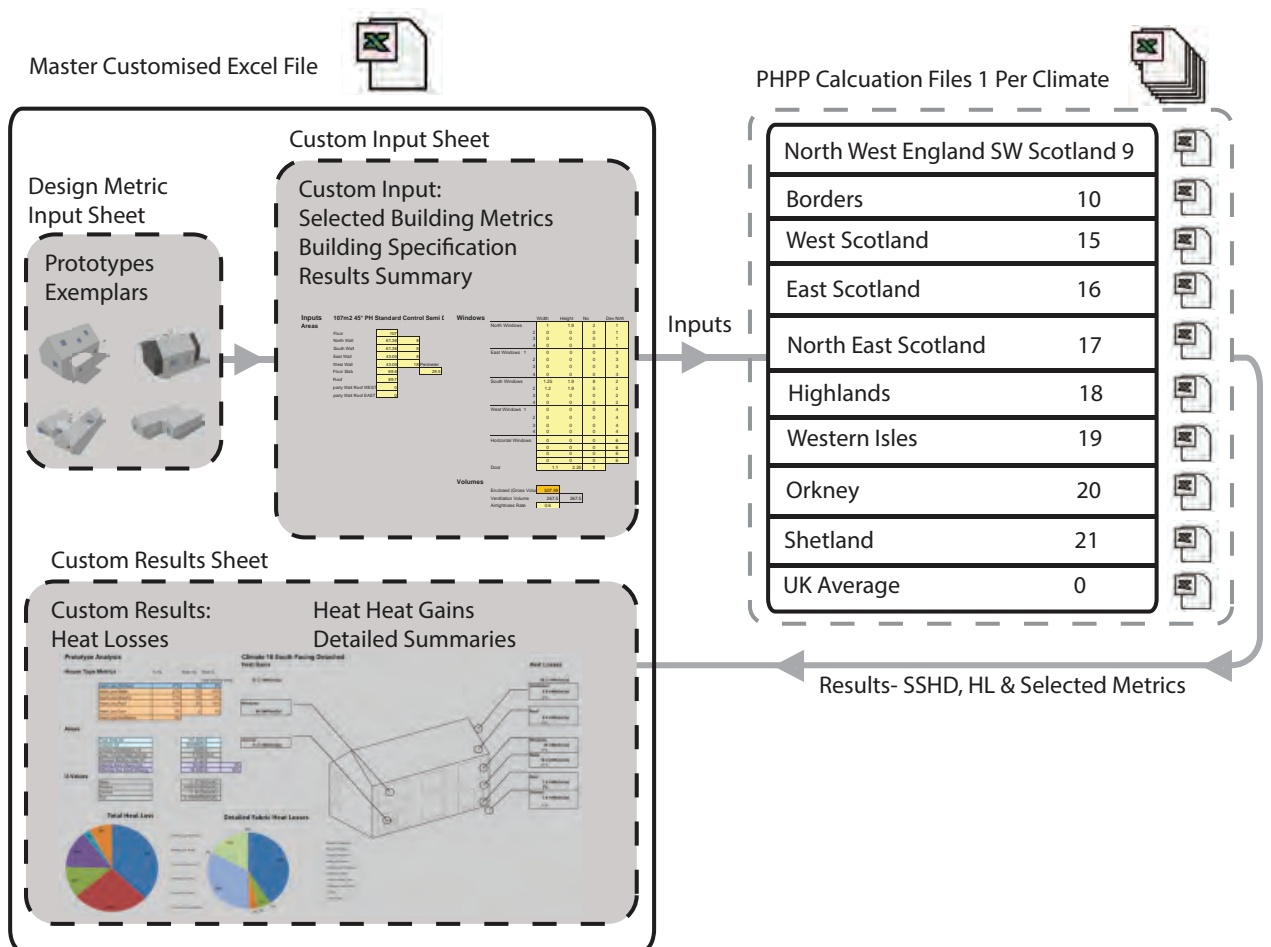
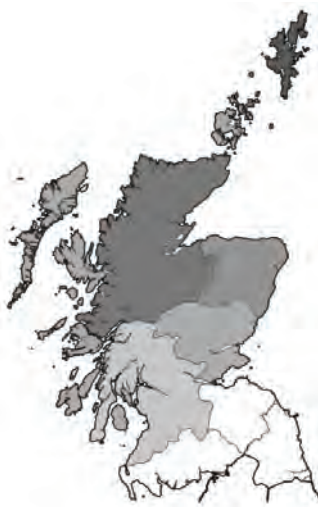


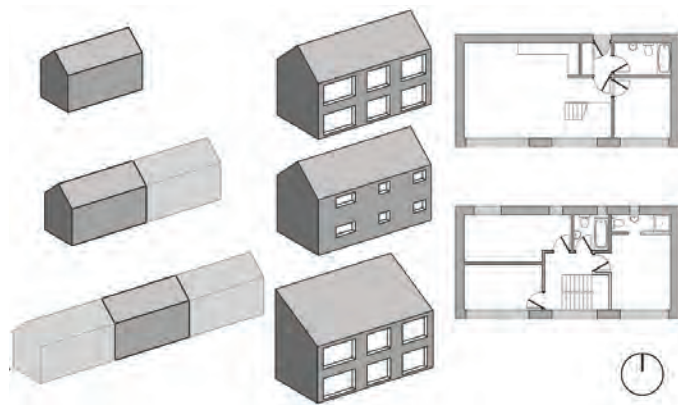
Figure 80- Schematic of linkages between input and output and the PHPP calculation files (Final Version)

QUANTITATIVE ANALYSIS OF BUILDING FORM AND POSITIONING ON SSHD OF ULEH IN SCOTLAND

Chapter 6



Scottish Climatic Regions Studied



Study Model & Variables

6. ANALYSIS OF REGIONAL CLIMATIC VARIATION ON SPECIFIC SPACE HEAT DEMAND OF A PROTOTYPE ULTRA-LOW ENERGY HOUSE IN SCOTLAND

The study quantifies the effect of varying key architectural parameters on the Specific Space Heat Demand (SSHD) of a ULEH across different Scottish climatic regions using PHPP. The SSHD is a key metric in determining the space heating energy efficiency as this represents the space heating requirement per m² per year. The chapter firstly presents an analysis of the climatic variation across Scotland. The remainder of the chapter is comprised of a series of SSHD analysis studies using the Passivhaus Planning Package (PHPP). For the majority of the studies a specially developed ULEH (Passivhaus) specification 107m² Doll's house prototype is analysed in a specifically developed custom PHPP master file to perform SSHD calculations. This prototype is a best practice design based on passive solar principles, discussed further in section 6.4. Firstly the study determines the variation in SSHD across the Scottish climate in the nine regional climate datasets supplied by the BRE for use in PHPP. Results of this study are used to determine weighted u-values for the extremes of Scottish climate which are used in later studies. The study uses PHPP to analyse the impact of building orientation, form and technical specification on the SSHD in the extremes of Scottish Climate.

The principle objectives of this study are to:

- Determine the effect of regional Scottish climate variations on SSHD of ULEH.
- Quantitatively establish how variations in building typology, form and orientation affect the SSHD across Scotland.
- Establish the impact that current UK and Scottish ZCH legislation specifications and assessment methodologies have on SSHD compared with the ULEH Passivhaus concept.

Study Overview

A preliminary study (Section 6.3) uses a basic 50m² prototype that benchmarks the methodology for the later studies. The first study (Section 6.4- 1A, 1B) which utilises a 107m² 'Doll's house' prototype quantifies the effect of varying building location on the space heating energy performance to establish the effect of regional Scottish climates on SSHD. The next set of studies (Section 6.5- 2A-2E) analyses alterations to the orientation and changes to the building and their effect on SSHD in the extremes of the Scottish climate. The final set of studies (Section 6.6- 3A, 3B) analyse the impact of fabric performance, MVHR and airtightness specifications defined for ZCH and Passivhaus.

Study Structure and Specific Variables

Figure 80] Gives a diagrammatic overview of the main studies 1,2 and 3. These studies all use the first revision of the customised master file discussed in Chapter 5.

[Figure 81 [Figure 82] Illustrates the basic study structure and Study Variables along with the notation used to reference the project and the relevant sections within the thesis.

The following section outlines the use of the variables and prototypes used in the thermal analysis.

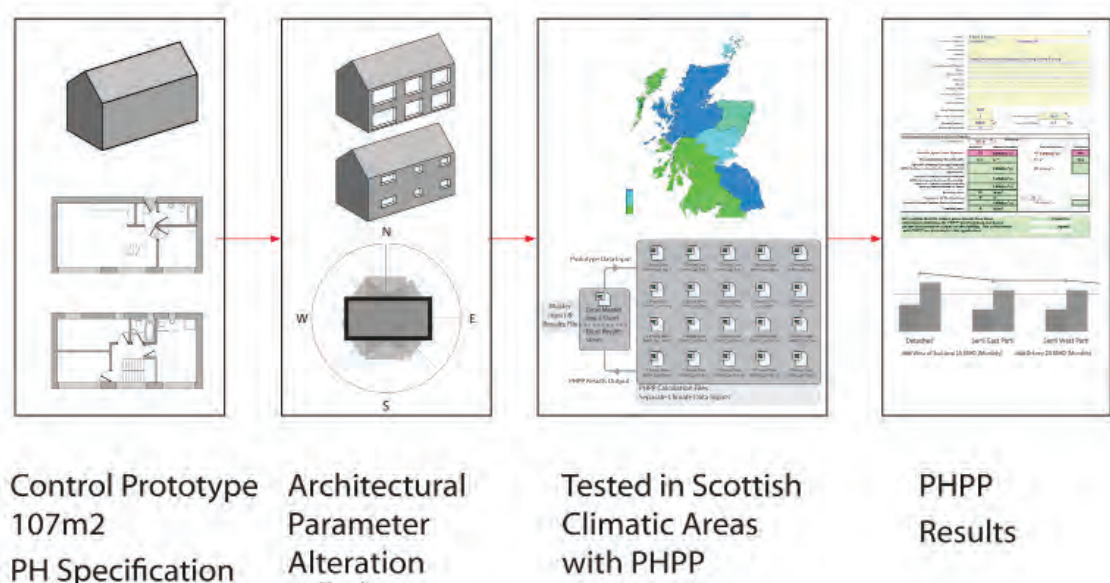


Figure 81- Basic Study Overview

Chapter 6- Study Structure

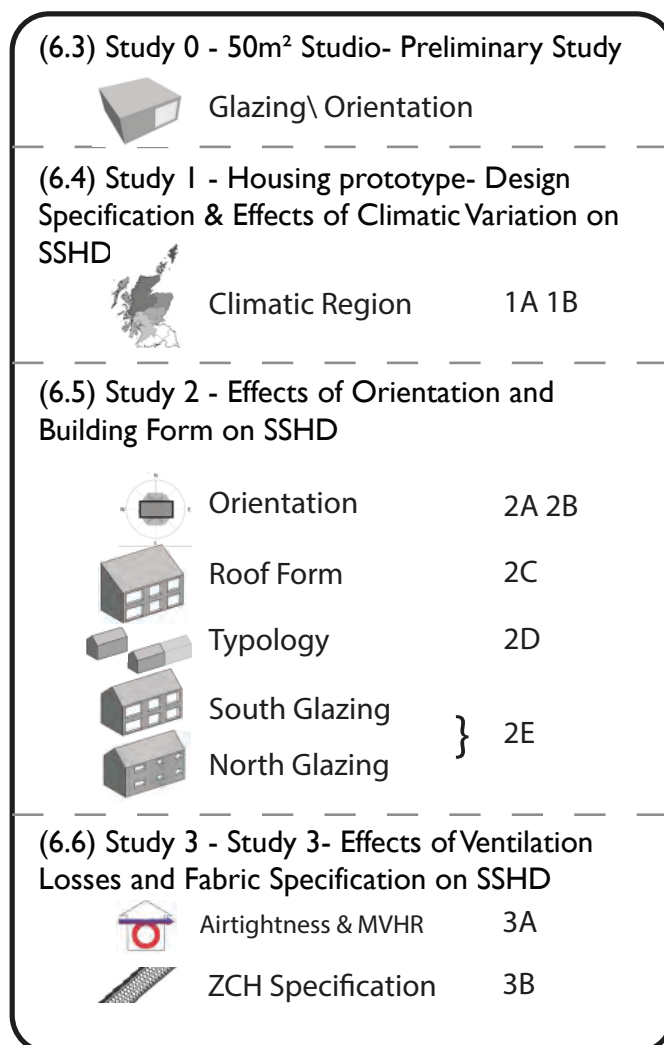


Figure 82- Study Variables, Study Notation and Sections

Section 6.3

Study 0, 50m² Studio

- Orientation
- Window Orientation
- Window Size
- Two Storey Plan Form

Section 6.4

Study 1- Housing prototype- Design Specification & Effects of Climatic Variation on SSHD Design methodology and technical specification

- Scottish Climatic Variation (1A)
- Average Climate Variation (1B)

Section 6.5

Study 2- Effects of Orientation and Building Form on SSHD

- Dwelling Orientation (2A)
- Orientation Fine Grain Analysis (2B)
- Roof Type and Roof Angle (2C)
- Dwelling Typology (2D)
- North & South Facade Fenestration (2E)

Section 6.6

Study 3- Effects of Ventilation Losses and Fabric Specification on SSHD

- Airtightness & MVHR Effect (3A)
- ZCH/FEES, ZCH/Advanced Specification and PH Fabric Performance specification comparison studies (3B)

6.1.Scottish Regional Climate Data

While Scotland has a comparatively small land mass there are significant regional differences in climate. Unlike central Europe, Scotland tends to have significantly more complex weather affected by factors such as; the maritime influence, the warm Gulf Stream affecting the west coast, a latitude range from 54.98°N to 60.38°N, complex, mountainous topography, very high average wind speeds and high rainfall. The Met Office divides Scotland into three climatic areas; North, East and West [Figure 83]. The visual analysis of the Scottish climate data provided by the Met Office illustrates the significant variation of climate across regions. Climatic variation significantly affects the performance of building sited within each of these regions, BRE uses nine separate regions, two of which are shared with England which gives a more accurate picture of regional differences in climate.



Figure 83- MET Office Regions

6.1.1. Met Office Meteorological Data

The Met Office are responsible for predicting, researching and providing detailed information about the weather in the UK.

The following data regarding the three regional climates of Scotland is from the following sections of the Met Office web page:

(Met Office 2013d) Western Scotland

(Met Office 2013c) Northern Scotland

(Met Office 2013b) Eastern Scotland

(Met Office 2013g) Climate Averages

(Met Office 2013e) Mapped Averages.

(Met Office 2013a) Download regional values

6.1.1.1. Geographic Influences

Northern Scotland

The Met Office determines the North of Scotland as; the Highlands, the Western Isles, Orkney and Shetland. The main geographic features are the Grampian Mountains and the northern Highlands, which rise from the glens and fjord-like sea lochs. It has extensive areas of high ground including the highest point in the UK, Ben Nevis (1344m). This region has the harshest climate within Scotland with the most rainfall, least sunshine and high average wind speeds.

Western Scotland

The Met Office defines the West of Scotland as Strathclyde, Central (except Clackmannanshire and Falkirk),

Dumfries and Galloway and the Argyll Islands. Much of this climatic region consists of ground more than 200m above sea level; in the north many peaks exceed 1000m. There is a strong maritime control of temperature which can be identified by the difference between average hot and cold temperatures. Western Scotland is generally wetter, more exposed to wind and has less sunshine than the East but has higher average temperatures.

Eastern Scotland

The Met Office defines the Eastern Scotland as the Borders, Lothian's, Falkirk, Clackmannanshire, Fife, Tayside and Grampian. The principle geographic features are the valleys and estuaries, the rivers; Tweed, Forth, Tay and Dee. The East of Scotland is the driest, sunniest and least exposed to wind area in Scotland but has generally lower temperatures than the West, due to the effects of the Gulf Stream.

6.1.1.2. Temperature

[Figure 84]

In all areas of Scotland, the minimum daily temperature is around sunrise and maximum is 2-3 hours after midday. January and February are generally the coldest months, while July and August are the hottest.

Northern Scotland

Mean temperature range

Low altitude 8.5°C (Moray Firth) to 7°C (Shetland)

High Altitude 0°C (Ben Nevis)

Significant variations can be seen from the combination of proximity to the coast and topography.

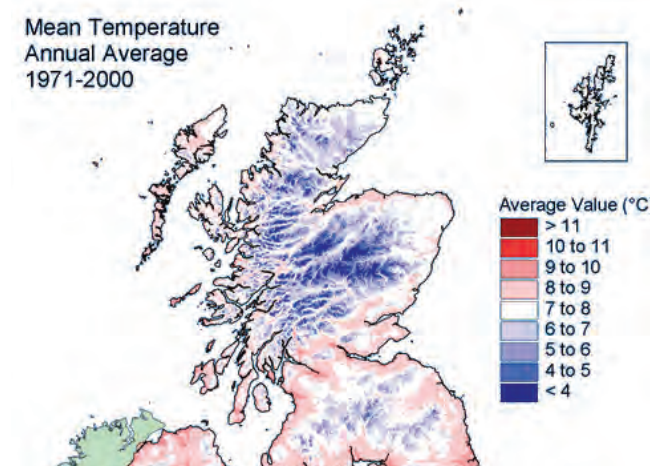


Figure 84- Mean Average Temperature

Western Scotland

Western Scotland is milder than the East of Scotland due to the maritime influence; prevailing winds are blown from the sea. The Gulf Stream also has a strong effect on the temperature. The smaller the range of temperature difference, the greater the maritime influence.

Mean temperature range

Coastal areas around 9.4°C to 9.7°C (Ayrshire, Bute and Kintyre)

Inland 8°C to 9.3°C

Eastern Scotland

Mean annual temperature range

9°C (Firth of Forth) to less than 6°C (high Grampians)

Significant Variations are seen from the combination of proximity to the coast, topography and urban development.

6.1.1.3. Heating Degree Days and Cooling Degree Days

Degree days are defined as the mean number of degrees by which the air temperature has gone above, or below, a threshold, calculated day by day and summed over a period of days. Days when the temperature has not gone above (or below) the threshold at any point in the day do not contribute to the total. Degree days give a good representation of the climate severity, as they are not just averages of temperature but a cumulative figure (Met Office 2013f). PHPP uses a variation of Degree days, but measuring number of degrees per hour below 15.5 °C per annum in (kKh/a)-Heating Degree Hours, the G_t value (Passivhaus Institut 2007).

Heating Degree Days

[Figure 85]

Heating Degree Hours per annum (kKh/a), detailed climate severity figure determining the number of degrees below 15.5°C per day per annum. This data illustrates the effect that the maritime influence has on coastal low lying areas, particularly on the West Coast and islands. The temperature difference altitude makes can also be clearly seen with areas of the highlands requiring more than 4000 heating degree days. Detailed analysis within regions the degree days reflect the topographic map of Scotland, due to the lower temperatures in the higher areas (Met Office 2013f).

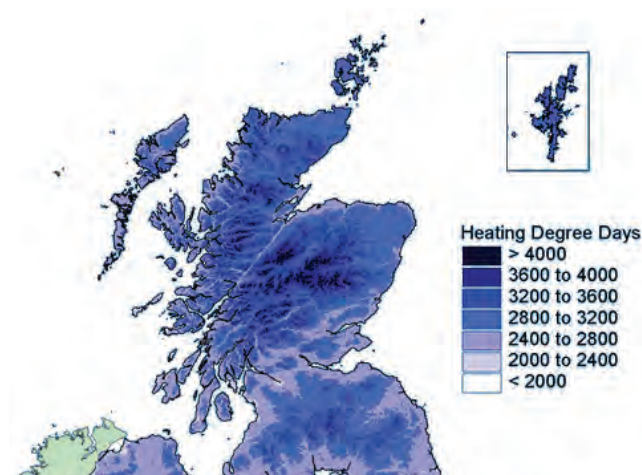


Figure 85- Heating Degree Days

Cooling Degrees Days

[Figure 86]

Cooling Degree Days per annum (kKh/a), detailed climate severity figure determining the number of degrees above 22°C per day per annum. This data illustrates the average days

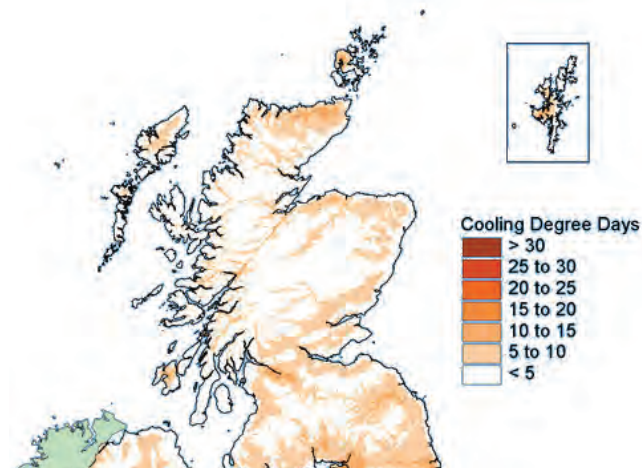


Figure 86- Cooling Degree Days

where the air temperature is above 22°C, and illustrates that there is a minimal need for cooling required when considering external air temperature across the year. It can be seen that areas a few miles inland of the coast and some central areas benefit from higher temperatures. (Met Office 2013f)

6.1.1.4. Sunshine

[Figure 87]

In general December has the least sunshine and May/June has the most. Sunshine decreases with distance from the coast, increasing altitude and latitude. Geographic features such as deep glens and north-facing slopes can also reduce the amount of sunshine hours.

Northern Scotland

- Most sun is 1300 hours per annum (Close to Moray Firth and southern outer Hebrides)
- Least sun is less than <1000 hours per annum (Shetland)

Eastern Scotland

- Fife has the most sun with 1500 hours per annum.
- Grampian Mountains has the least sun with less than 1100 hours

Western Scotland

- The area with the most sun is the Solway coast, Kintyre with 1450 hours
- The two areas with the least sun are the Southern Uplands with 1200 hours and the West Highlands with 1100 hours per annum.

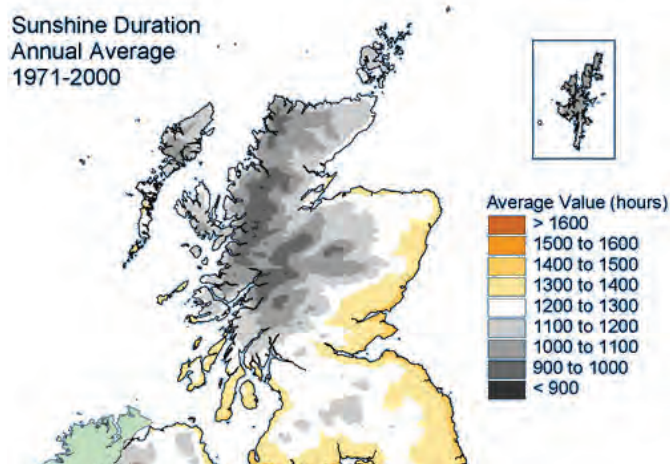


Figure 87- Average Sunshine Duration

6.1.1.5. Wind

[Figure 88]

There is a significant variance in wind patterns and their strength and frequency across Scotland. However, the airtightness values in ultra-low Energy housing make infiltration through unwanted drafts a minimal issue but more important in housing with lower fabric specifications and consequently higher air infiltration issues. The western and northern

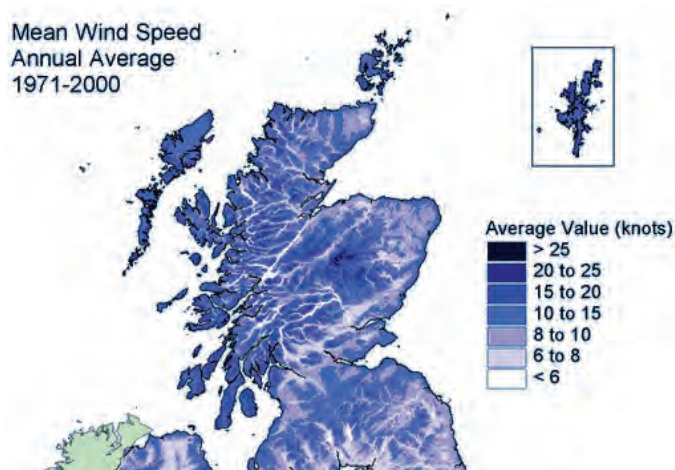


Figure 88- Mean Average Wind Speed

parts of Northern Scotland are, on average, the windiest in the UK, being fully exposed to the Atlantic and closest to the passage of areas of low pressure. The penetration of westerly winds into eastern Scotland is controlled largely by topography, with the Central Lowlands assisting this but the higher ground either side providing shelter. West Scotland is one of the more exposed areas of the UK. This is a result of being close to the Atlantic which can carry strong westerly winds.

6.1.1.6. Rainfall

[Figure 89]

This data very clearly illustrates the large variation between the East and West of Scotland, with major increase in rainfall over higher ground to the west of Scotland. The low lying east coast has significantly less rainfall. Moist air that is forced to ascend hills may be cooled to the dew point to produce cloud and rain. A map of average annual rainfall therefore looks similar to a Topographic map. The wettest months tend to be in autumn and early winter, whereas late winter and spring are normally the driest seasons of the year. As discussed previously this has traditionally influenced variations in building detailing.

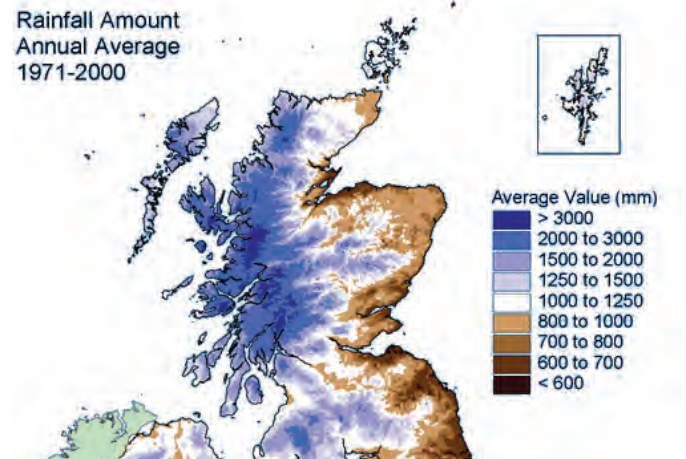


Figure 89- Average Annual Rainfall

Much of Northern Scotland is exposed to the rain-bearing westerly winds, particularly the Western Isles and the West Coast

- Average Rainfall 1700mm(western half of the region)
- Highest Rainfall 4000mm (NW Fort William)

Much of Eastern Scotland is sheltered from the rain-bearing westerly winds

- Lowest Rainfall 700mm (East Lothian, Fife and the Moray Firth)
- Highest Rainfall 1500mm (Southern Grampians)

West of Scotland receives more significantly more rainfall than the East of Scotland

- Least Rainfall 1000 mm (upper Clyde valley and coast areas of Ayrshire and Dumfries and Galloway)
- Highest Rainfall >3500mm (high West Highlands)

6.1.2. Summary of BRE Climate Data Input

[Figure 90]

The BRE produces nine climatic areas for Scotland (BRE 2011c) (listed below);

- North West England SW Scotland 9
- Borders 10
- West Scotland 15
- East Scotland 16
- North East Scotland 17
- Highlands 18
- Western Isles 19
- Orkney 20
- Shetland 21

The locations of the climate data weather stations are shown in red. However, the climate data weather station for the borders (10) appears to be situated in the South West climate data (9).

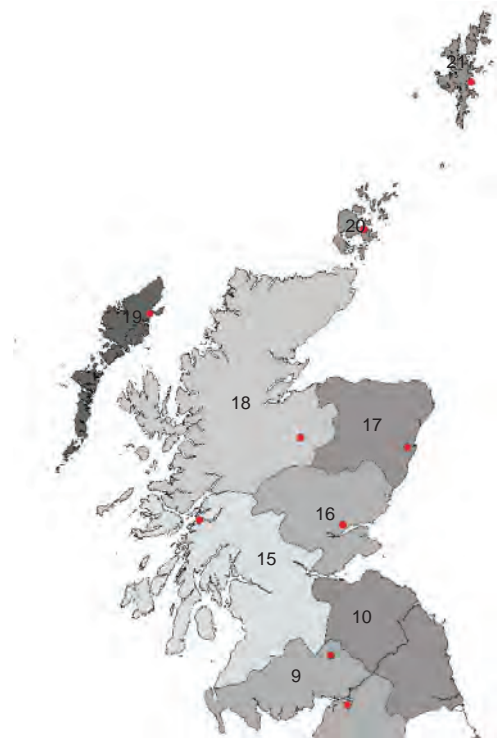


Figure 90- BRE Climate Data Areas (BRE 2011c)

Influential Factors

[Figure 91a/b] illustrates the solar insolation and Gt value for all of the BRE climate data.

An analysis of the BRE climate data for Scotland demonstrated that the most influential factors are the solar insolation totals and the heating degree hours per annum (Gt value). These figures broadly represent the possible heat gains due to climate (Solar Insolation) and the magnitude of the heat losses (Gt value). Solar insolation is the energy from the sun falling on a given surface and it is measured in kWh/(m²a). An added complication to this is the time of year in which the solar gains are available and when they can be utilised, this is taken into account through a utilisation figure generated by PHPP, so the two figures cannot be used to estimate SSHD.

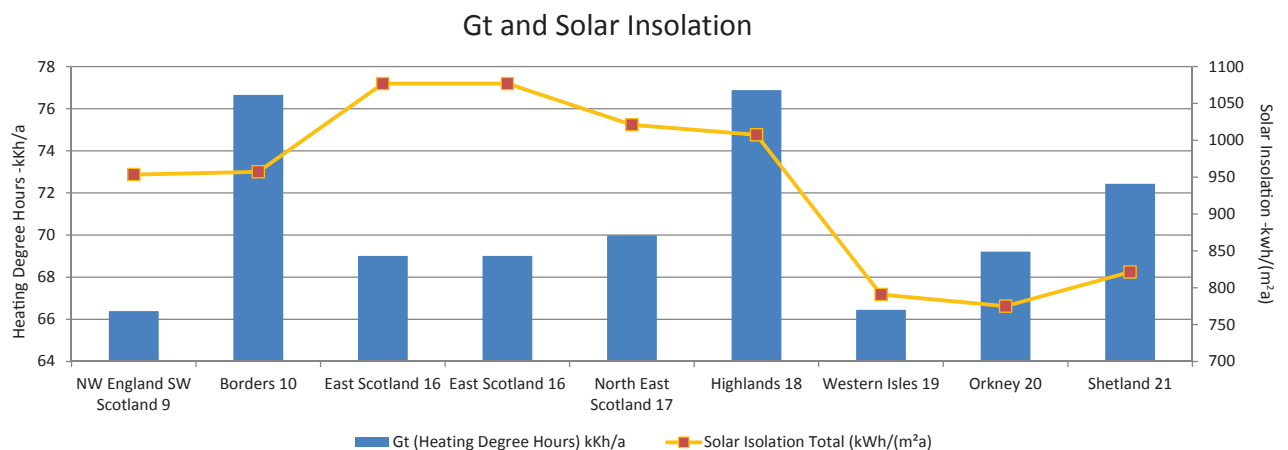


Figure 91a- Calculated Averages, Gt and Solar Insolation Graph (BRE 2011c)

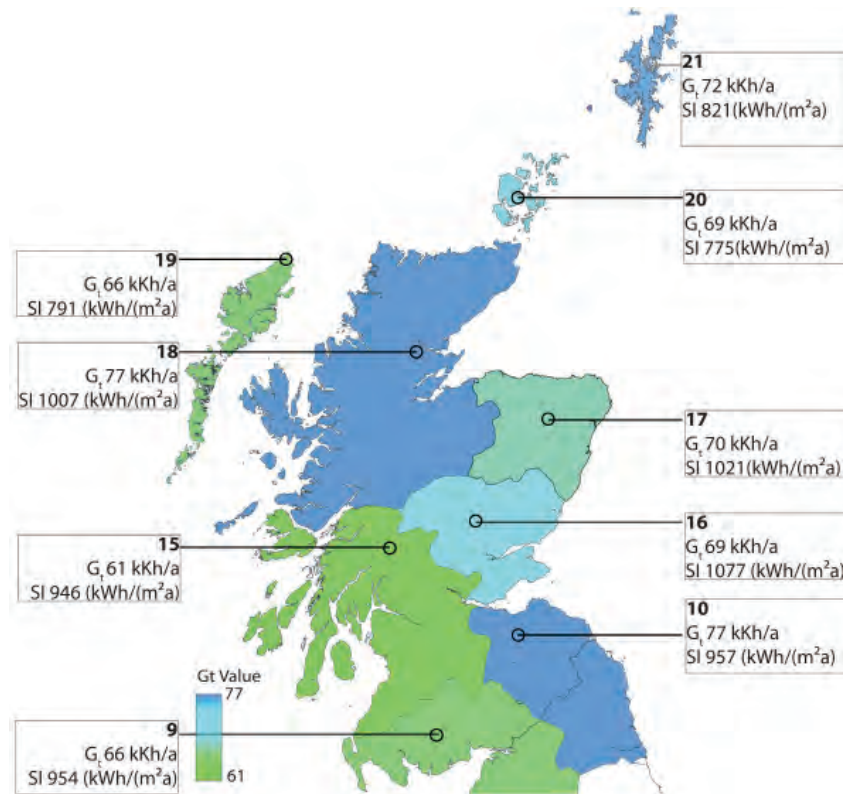


Figure 91b- Calculated Averages, Gt and Solar Insolation Map (BRE 2011c)

Solar insolation

According to the BRE climate data, the most available total solar irradiation is available in the East of Scotland (1077 (kWh/(m²a))), which coincides with the Met Office figure of 1500 hours for Fife.

The BRE climate data determines Orkney (20) to have the least solar irradiation, which differs from the Met Office data, defining the Shetlands as the least sunshine hours (<1000 hours).

Heating Degree Hours per annum

The regions with the highest Heating Degree Hours per annum, therefore the coldest regarding temperature below 15°C for the greatest number of hours are the Borders (10) and the Highlands (18) at 77kKh/a. The region with the lowest Heating Degree Hours is the West of Scotland (15) with 61kKh/a.

6.2. Standard PHPP Excel Calculation Sheets

The following section briefly discusses the standard PHPP input, output and weather data Excel Spread sheets. The customised methodology discussed in Chapter 5 simplifies the data entry that is required across many of these sheets and allows multiple scenarios to be tested quickly. Although the customised methodology still requires limited amounts of data to be entered into the standard PHPP file.

The standard PHPP requires detailed numerical information regarding all aspects of the building form and construction. PHPP uses a yellow highlight to denote the identification of input cells. Many of the sheets within PHPP are used to both input data and to display data. There is a large amount of data input and output options in PHPP. The following section explains the values used in the input and results sheets with a brief explanation of the input data.

The PHPP only requires limited data input in selected sheets to calculate thermal performance, therefore the studies will only utilise selected data required for the calculation of SSHD and heat load (Passivhaus Institut 2007, p.30). Further data inputs can be used to generate information regarding electrical energy use and domestic hot water. The data input used in this study would not fully specify the dwelling for full Passivhaus certification as it does not include Primary Energy, Domestic Hot Water or Thermal Bridging information. However the data entered for the studies produces an accurate comparison between the study variables with regard to the thermal performance. The software will operate in Verification mode, which uses some default values such as occupants and internal heat gains. The PHPP calculation files will utilise the monthly method analysis mode rather than the annual method mode, both are suitable for certification. The majority of the technical specification of the dwelling prototypes is fixed throughout. This covers; window frame, glazing, sizing, ground floor buildup and mechanical ventilation system specifications.

6.2.1. Input Sheets

The PHPP is based on a series of input sheets that also provide calculation and summary information. The calculation sheets will either data entry directly into the PHPP or any data that varies will be reference from the customised PHPP master file. The results sheets contain data that will be linked to and displayed in the customised PHPP master file.

Building:	4 Bed 2 Storey	
Location and Climate:	Scotland	West Scotland 15
Street:		
Postcode/City:		
Country:		
Building Type:	Semi Detached Rectangular 2 Storey South Facing	
Home Owner(s) / Client(s):		
Street:		
Postcode/City:		
Architect:		
Street:		
Postcode/City:		
Mechanical System:		
Street:		
Postcode/City:		
Year of Construction:	2011	
Number of Dwelling Units:	1	
Enclosed Volume $V_{e,i}$:	539.2	m ³
Number of Occupants:	2.9	
Interior Temperature:	20.0	°C
Internal Heat Gains:	2.1	W/m ²

No Standard Climate

Calculation Electricity / Internal Heat Gains

Building Type:

Internal Heat Gains

Utilisation Pattern:

Type of Values Used:

Planned Number of Occupants:

4 Verification

Specific Demands with Reference to the Treated Floor Area			
Treated Floor Area:	102.9	m ²	
Applied:	Monthly Method	PH Certificate:	Fulfilled?
Specific Space Heat Demand:	14	kWh/(m ² a)	Yes
Pressurization Test Result:	0.6	h ⁻¹	Yes
Specific Primary Energy Demand (DHW, Heating, Cooling, Auxiliary and Household Electricity):		kWh/(m ² a)	
Specific Primary Energy Demand (DHW, Heating and Auxiliary Electricity):		kWh/(m ² a)	
Specific Primary Energy Demand Energy Conservation by Solar Electricity:		kWh/(m ² a)	
Heating Load:	9	W/m ²	
Frequency of Overheating:	0	%	
Specific Useful Cooling Energy Demand:		kWh/(m ² a)	
Cooling Load:	0	W/m ²	

We confirm that the values given herein have been determined following the PHPP methodology and based on the characteristic values of the building. The calculations with PHPP are attached to this application.

Issued on: _____

Signed: _____

Verification:	Monthly Method	
	Specific Space Heat Demand, Annual Method	13.3
	Specific Space Heat Demand, Monthly Method	14.0

Figure 92- Typical Verification Summary Sheet (Passivhaus Institut 2007)

6.2.1.1. Verification Sheet

[Figure 92]

Serves as the cover sheet for PHPP demonstrating the compliance for certification criteria.

Values that vary between studies:

- House information
- House Volume
- Occupant Design Size

6.2.1.2. Areas Sheet

Requires all of the sizes and types of the thermal envelope minus the information for the windows. All figures are generated from a three dimensional sketchup model and AutoCAD drawings. [Figure 93] illustrates the typical detached Doll's house model data entry in the Areas sheet used for the majority of the studies described in more detail in section 6.4.

Values that vary between studies

- Envelope Areas, External Walls, Roof and Front Door. All measurements taken from the outside measurements.
- Treated floor area TFA is the net living area within the building's thermal envelope; this does not include areas under stairs. Non habitable rooms such as stores count as 60% of floor area and

Building **4 Bed 2 Story** Heat Demand **11** kWh/(m²a)

Summary						Building Element Overview	Average U-Value [W/(m²K)]
Group Nr.	Area Group	Temp Zone	Area	Unit	Comments		
1	Treated Floor Area		107.00	m²	Living area or useful area within the thermal envelope		
2	North Windows	A	3.80	m²	Results are from the Windows worksheet.	North Windows	0.851
3	East Windows	A	0.00	m²		East Windows	
4	South Windows	A	30.40	m²		South Windows	0.823
5	West Windows	A	0.00	m²		West Windows	
6	Horizontal Windows	A	0.00	m²		Horizontal Windows	
7	Exterior Door	A	2.48	m²	Please subtract area of door from respective building element	Exterior Door	0.810
8	Exterior Wall - Ambient	A	174.62	m²	Window areas are subtracted from the individual areas specified in the "Windows" worksheet.	Exterior Wall - Ambient	0.117
9	Exterior Wall - Ground	B	0.00	m²	Temperature Zone "A" is ambient air.	Exterior Wall - Ground	
10	Roof/Ceiling - Ambient	A	89.70	m²	Temperature zone "B" is the ground.	Roof/Ceiling - Ambient	0.117
11	Floor Slab	B	69.60	m²		Floor Slab	0.181
12			0.00	m²	Temperature zones "A", "B", "P" and "X" may be used. NOT "I"		
13			0.00	m²	Temperature zones "A", "B", "P" and "X" may be used. NOT "I"		
14		X	0.00	m²	Temperature zone "X": Please provide user-defined reduction factor (0 < f, < 1):	Factor for X	75%
						Thermal Bridge Overview	▼ (W/(mK))
15	Thermal Bridges Ambient	A	0.00	m	Units in m	Thermal Bridges Ambient	
16	Perimeter Thermal Bridges	P	0.00	m	Units in m; temperature zone "P" is perimeter (see Ground worksheet).	Perimeter Thermal Bridges	
17	Thermal Bridges Floor Slab	B	0.00	m	Units in m	Thermal Bridges Floor Slab	
18	Partition Wall to Neighbour	I	0.00	m²	No heat losses, only considered for the heat load calculation.	Partition Wall to Neighbour	
Total Thermal Envelope						Average Therm. Envelope	0.199

Area Input																Selection of the Corresponding Building Element Assembly	Nr.	U-Value [W/(m²K)]
Area Nr.	Building Element Description	Group Nr.	Assigned to Group	Quantity	x (a [m]	x	b [m]	+	User-Determined [m²]	-	User Subtraction [m²]	-	Subtraction Window Areas [m²]	=				Area [m²]
	Treated Floor Area	1	Treated Floor Area	1	x (		x		+	107.00	-				=	107.0		
	North Windows	2	North Windows													3.8		0.851
	East Windows	3	East Windows													0.0		0.000
	South Windows	4	South Windows													30.4		0.823
	West Windows	5	West Windows													0.0		0.000
	Horizontal Windows	6	Horizontal Windows													0.0		0.000
	Exterior Door	7	Exterior Door			1.10	x	2.25	+		-					2.5		0.81
1	North Wall	8	Exterior Wall - Ambient	1	x (		x		+	61.36	-					3.8	With Hairs	▼ 1 0.117
2	South Wall	8	Exterior Wall - Ambient	1	x (		x		+	61.36	-					30.4	With Hairs	▼ 1 0.117
3	East Wall(Parti)	8	Exterior Wall - Ambient	1	x (		x		+	43.05	-					0.0	With Hairs	▼ 1 0.117
4	West Wall	8	Exterior Wall - Ambient	1	x (		x		+	43.05	-					0.0	With Hairs	▼ 1 0.117
5	Floor Slab	11	Floor Slab	1	x (		x		+	69.60	-					0.0	Ground Hairs	▼ 4 0.181

Figure 93- Typical Areas Sheet (Passivhaus Institut 2007)

spaces between 1000mm and 2000mm count as 50% of floor area. This follows the Passivhaus German methodology used to calculate treated floor area; German Floor Area Ordinance (Wohnflächenverordnung [WofIV]) (Passivhaus Institut 2007).

Fixed for all studies (unless otherwise stated)

- Selection of wall build-up and U-Value (From U-Value Sheet),
- Presumed thermal Bridge Free Construction, no inputs required

6.2.1.3. U-Values Sheet

[Figure 94]

This sheet defines the u-value (thermal performance) and thickness of construction build-ups. The standard version of PHPP will calculate u-values and build up thicknesses using each building element's thermal transmittance value (λ [W/(mK)] and thickness. The calculation also requires the Heat Transfer Resistance (m^2K/W) Rsi and Rse values. However the customised version of the PHPP calculation file references both the u-value and thickness directly from the master file. This allows for the entry of an exact u-value figure from the master input file without using the calculation method.

Inputs Fixed for all studies

Specification

Solid Ground Floor build up

- Thickness: 276mm

- U-Value: 0.151 W/ (m²K)

Proprietary timber frame wall & roof buildup

140mm+ 75mm extruded closed cell polystyrene insulation

- Thickness: 341mm
- U-Value: 0.117 W/ (m²K)

These variables are fixed for the majority of the first research study unless otherwise stated. The other studies use weighted u-values to achieve the Passivhaus SSHD of 15 kWh/(m²a) in the climatic region.

Building: End-of-Terrace Passive House Kranichstein

Wedge Shaped Building Element Layers and
Still Air Spaces -> Secondary Calculation to the Right

1 Exterior wall

Assembly No. Building Assembly Description

Heat Transfer Resistance [m²K/W]

interior R_{si}: 0.13

exterior R_{se}: 0.04

Area Section 1	λ [W/(mK)]	Area Section 2 (optional)	λ [W/(mK)]	Area Section 3 (optional)	λ [W/(mK)]	Total Width Thickness [mm]
1. Interior plaster	0.350					15
2. Calcium Silicate Block	1.100					175
3. Polystyrene Foam	0.040					275
4. Exterior Render	0.800					20
5.						
6.						
7.						
8.						

Percentage of Sec. 2

Percentage of Sec. 3

Total

48.5

cm

U-Value: 0.138 W/(m²K)

2 Roof

Assembly No. Building Assembly Description

Heat Transfer Resistance [m²K/W]

interior R_{si}: 0.10

exterior R_{se}: 0.04

Area Section 1	λ [W/(mK)]	Area Section 2 (optional)	λ [W/(mK)]	Area Section 3 (optional)	λ [W/(mK)]	Total Width Thickness [mm]
1. Chipboard	0.130					50
2. Blown Mineral Wool	0.040	I-Beam	0.374			400
3. Gypsum Plasterboard	0.700					13
4.						

Figure 94- Typical U- Values Sheet (Passivhaus Institut 2007)

Passive House Planning

HEAT LOSSES VIA THE GROUND

Ground Characteristics				Climate Data			
Thermal Conductivity	λ	2.0	W/(mK)	Av. Indoor Temp. Winter	T_i	20.0	°C
Heat Capacity	ρC	2.0	MJ/(m³K)	Av. Indoor Temp. Summer	T_i	25.0	°C
Periodic Penetration Depth	δ	3.17	m	Average Ground Surface Temperature	$T_{g,ave}$	11.0	°C
				Amplitude of $T_{g,ave}$	$T_{g,\Delta}$	4.3	°C
				Length of the Heating Period	n	6.7	months
				Heating Degree Hours - Exterior	G_e	61.0	kKh/a

Building Data				Floor Slab Data			
Floor Slab Area	A	128.7	m²	Floor Slab U-Value	U_f	0.151	W/(m²K)
Floor Slab Perimeter	P	57.2	m	Thermal Bridges at Floor Slab	$\Psi_{B'1}$	0.00	W/K
Character. Dimension of Floor Slab	B'	4.50	m	Floor Slab U-Value incl. TB	U_f'	0.151	W/(m²K)
				Eq. Thickness Floor	d_f	13.2	m

Floor Slab Type (select only one)			
<input type="checkbox"/> Heated Basement or Underground Floor Slab		<input type="checkbox"/> Unheated basement	
<input checked="" type="checkbox"/> Slab on Grade		<input type="checkbox"/> Suspended Floor	

For Basement or Underground Floor Slab				For Suspended Floor			
Basement Depth	z		m	U-Value Belowground Wall	U_{wB}		W/(m²K)
Additionally for Unheated Basements				Height Aboveground Wall	h		m
Air Change Unheated Basement	n	0.20	h⁻¹	U-Value Aboveground Wall	U_{wV}		W/(m²K)
Basement Volume	V		m³	U-Value Basement Floor Slab	U_{fB}		W/(m²K)

For Perimeter Insulation for Slab on Grade				For Suspended Floor			
Perimeter Insulation Width/Depth	D	0.71	m	U-Value Crawl Space	U_{Crawl}		W/(m²K)
Perimeter Insulation Thickness	d_n	0.10	m	Height of Crawl Space Wall	h		m
Conductivity Perimeter Insulation	λ_n	0.020	W/(mK)	U-Value Crawl Space Wall	U_{wV}		W/(m²K)
Location of the Perimeter Insulation (check only one field)	horizontal	<input type="checkbox"/>		Area of Ventilation Openings	ΣP		m²
	vertical	<input checked="" type="checkbox"/>		Wind Velocity at 10 m Height	v	4.0	m/s
				Wind Shield factor	f_W	0.05	-

Additional Thermal Bridge Heat Losses at Perimeter				Steady-State Fraction			
Phase Shift	β		months	Steady-State Fraction	$\Psi_{P,stat}^*I$	0.000	W/K
				Harmonic Fraction	$\Psi_{P,harm}^*I$	0.000	W/K

Groundwater Correction				Transm. Belowground El. (w/o Ground)			
Depth of the Groundwater Table	z_w	3.0	m	Transm. Belowground El. (w/o Ground)	L_{wg}	19.44	W/K
Groundwater Flow Rate	q_w	0.05	m/d	Relative Insulation Standard	d/B'	2.94	-
				Relative Groundwater Depth	z_w/B'	0.67	-
Groundwater Correction Factor	G_w	1.0021505	-	Relative Groundwater Velocity	I/B'	0.18	-

Figure 95- Typical Ground Sheet (Passivhaus Institut 2007)

6.2.1.4. Ground Sheet

[Figure 95]

Determines ground conditions and foundation design.

Inputs Fixed for all studies:

Slab on grade assumed

Perimeter Insulation:

- Width: 0.71m
- Thickness : 0.1m
- Thermal Conductivity: 0.02 W/(mk)

Varies between studies:

- Floor Slab area (m²) and perimeter (m²) values which are taken from the master file

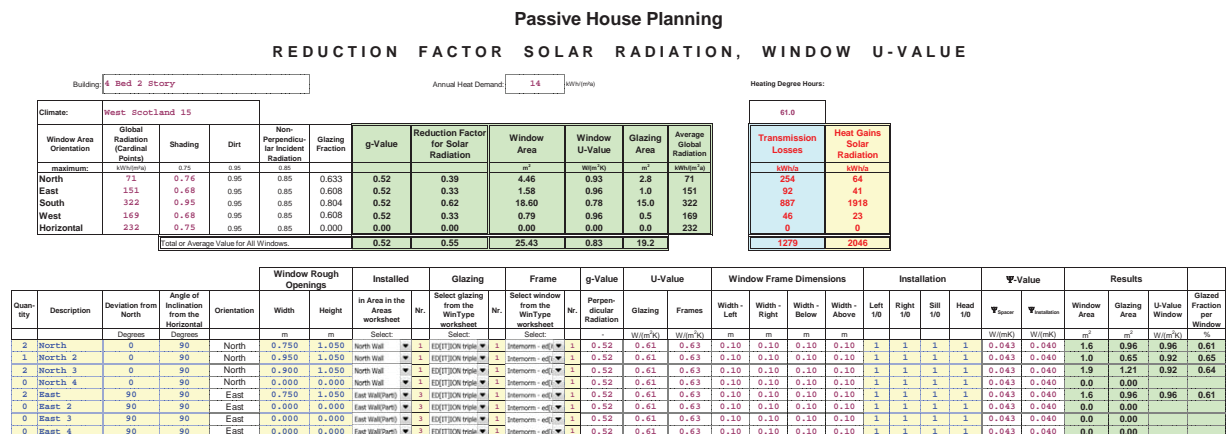


Figure 96- Typical Windows Sheet (Passivhaus Institut 2007)

6.2.1.5. Windows Sheet

[Figure 96]

Calculates the window and glazing area, Window U-Value and Glazed Fraction per Window.

Fixed for all studies:

Definition of Window and Frame (From Win Type Sheet)

- Window glazing-ED[IT]ION triple Glazed,
- Window Frame-Passivhaus Defined No.36 Internorm ED[IT]ION Passiv

Varies between studies:

- Orientation and angle of windows
- Size of individual windows
- Relationship between window installation

6.2.1.6. WinType Sheet

Determines the technical specification of window frames and glazing. PHPP then works out an average U-value based on the frame and glazing. The average U-value for the prototype is around 0.82 W/(m²K) using the specification below.

Fixed for all studies:

Specification of Window glazing:

- ED[IT]ION triple Glazed,
- G-Value 0.52
- Ug-Value 0.61 W/(m²K)

Specification of Window Frame

- Y-Spacer: 0.043
- Uf Value: 0.63
- Y-Installation: 0.04

Passive House Planning CALCULATING SHADING FACTORS

Climate: West Scotland 15
Building: 4 Bed 2 Storey
Latitude: 56.467 °

Orientation	Glazing Area m ²	Reduction Factor r _s
North	2.82	76%
East	0.96	68%
South	14.96	95%
West	0.48	68%
Horizontal	0.00	100%

Quantity	Description	Deviation from North	Angle of Inclination from the Horizontal	Orientation	Glazing Width	Glazing Height	Glazing Area	Height of the Shading Object	Horizontal Distance	Window Reveal Depth	Distance from Glazing Edge to Reveal	Overhang Depth	Distance from Upper Glazing Edge to Overhang	Additional Shading Reduction Factor	Horizontal Shading Reduction Factor	Reveal Shading Reduction Factor	Overhang Shading Reduction Factor	Total Shading Reduction Factor
		Degrees	Degrees		m	m	A _G	m	m	m	m	m	m	%	%	%	%	%
2	North	0	90	North	0.56	0.86	1.0			0.20	0.050	0.20	0.05	100%	100%	84%	88%	74%
1	North 2	0	90	North	0.76	0.86	0.7			0.20	0.050	0.20	0.05	100%	100%	87%	88%	77%
2	North 3	0	90	North	0.71	0.86	1.2			0.20	0.050	0.20	0.05	100%	100%	87%	88%	76%
0	North 4	0	90	North	-0.19	-0.19	0.0			0.20	0.050	0.20	0.05	100%	100%	571%	466%	2637%
2	East	90	90	East	0.56	0.86	1.0			0.20	0.050	0.20	0.05	100%	100%	76%	89%	68%
0	East 2	90	90	East	-0.19	-0.19	0.0			0.20	0.050	0.20	0.05	100%	100%	1032%	350%	3613%
0	East 3	90	90	East	-0.19	-0.19	0.0			0.20	0.050	0.20	0.05	100%	100%	1032%	350%	3613%
0	East 4	90	90	East	-0.19	-0.19	0.0			0.20	0.050	0.20	0.05	100%	100%	1032%	350%	3613%
4	South	180	90	South	1.11	0.86	3.8			0.20	0.050	0.20	0.05	100%	100%	94%	97%	91%
2	South 2	180	90	South	0.71	0.86	1.2			0.20	0.050	0.20	0.05	100%	100%	94%	97%	91%

Figure 97- Typical Shading Sheet (Passivhaus Institut 2007)

6.2.1.7. Shading Sheet

[Figure 97]

It has been noted that the shading calculations with zero quantity windows present an error figure. However this does not affect results.

Fixed for all studies:

All shading factors for building, including window reveals and overhangs

- Window Reveal Depth- 0.20
- Distance from Glazing Edge to Reveal- 0.050
- Overhang Depth- 0.20
- Distance from Upper Glazing Edge to Overhang- 0.05
- Additional Shading Reduction Factor- 100%
- The study assumes no over shadowing site features

Varies between studies:

Calculates Shading factor reductions for all windows

6.2.1.8. Summer Shading Sheet

Temporary factor for reduction of solar gain in summer e.g. blinds.

Fixed for all studies:

- All south facing windows have a 50% effective temporary solar shading device to prevent overheating and to keep maximum temperature swing of less than 3 Kelvin (PHPP guidance).
- All other windows have no temporary solar shading.

6.2.1.9. Ventilation Sheet

[Figure 98]

Detailed specification of Ventilation System, definition of MVHR unit and air duct lengths. The room ventilation requirements are Fixed for all studies.

Fixed for all studies:

- Assumed Novus 300- 91.4% Efficient Heat Recovery Unit
- Assumed airtightness figure of: n50 of 0.6 h⁻¹ @ 50 Pa
- MVHR Unit within Thermal Envelope
- 1 bathroom
- 1 kitchen
- Exhaust Duct Length 1.1.m
- Extract Duct Length 1.5m
- Unit inside Thermal Envelope
- Balanced PH Ventilation

Varies between studies:

- Net Air Volume for Pressure test
- Specification of rooms requiring ventilation
- Airtightness Value Constant at 0.6 unless stated in study

6.2.1.10. Summer Sheet

[Figure 99]

The summer sheet defines the thermal mass specification and ventilation strategies. A nominal 1.49 1/h for summer ventilation was calculated for all studies from the summer ventilation sheet.

Fixed for all studies:

- Specification of building heat capacity (thermal mass): Assumed as lightweight construction, 60 W/(m²K)
- Air Change Rate by Natural (Windows & Leakages) or Exhaust-Only Mechanical Ventilation 1.49 1/h
- Mechanical Ventilation Summer 0.31/h

Passive House Planning

VENTILATION DATA

Building: **End-of-Terrace Passive House Kranichstein**

Treated Floor Area A_{TFA}	m ²	156	(Areas worksheet)
Room Height h	m	2.5	(Annual Heat Demand worksheet)
Room Ventilation Volume ($A_{TFA} \cdot h$) = V_V	m ³	390	(Annual Heat Demand worksheet)

Ventilation System Design - Standard Operation

Occupancy	m ² /P	35				
Number of Occupants	P	4.5				
Supply Air per Person	m ³ /(P*h)	30				
Supply Air Requirement	m ³ /h	134				
Extract Air Rooms			Kitchen	Bathroom	Shower	WC
Quantity			1	1	1	1
Extract Air Requirement per Room	m ³ /h	60	40	20	20	
Total Extract Air Requirement	m ³ /h	140				

Design Air Flow Rate (Maximum) m³/h **152**

Average Air Change Rate Calculation

Type of Operation	Daily Operation Duration h/d	Factors Referenced to Maximum	Air Flow Rate m ³ /h	Air Change Rate 1/h
Maximum		1.00	152	0.39
Standard	24.0	0.77	117	0.30
Basic		0.54	82	0.21
Minimum		0.40	61	0.16
<input checked="" type="checkbox"/> Residential Building	Average value	0.77	Average Air Flow Rate (m ³ /h) 117	Average Air Change Rate (1/h) 0.30

Infiltration Air Change Rate according to EN 13790

Wind Protection Coefficients According to EN 13790		
Coefficient e for Screening Class	Several Sides Exposed	One Side Exposed
No Screening	0.10	0.03
Moderate Screening	0.07	0.02
High Screening	0.04	0.01
Coefficient f	15	20

Wind Protection Coefficient, e	for Annual Demand: 0.07	for Heat Load: 0.18		
Wind Protection Coefficient, f	15	15	Net Air Volume for Press. Test V_{n50}	Air Permeability q_{50}
Air Change Rate at Press. Test n_{50}	1/h 0.22	0.22	480 m ³	0.27 m ³ /(hm ²)

Type of Ventilation System

<input checked="" type="checkbox"/> Balanced PH Ventilation	Please Check	for Annual Demand:	for Heat Load:
Pure Extract Air			
Excess Extract Air		1/h 0.00	0.00
Infiltration Air Change Rate $n_{V,Res}$		1/h 0.019	0.047

Effective Heat Recovery Efficiency of the Ventilation System with Heat Recovery

<input checked="" type="checkbox"/> Central unit within the thermal envelope.				
Central unit outside of the thermal envelope.				
Efficiency of Heat Recovery η_{HR}		0.83	Heat Recovery Unit	
Transmittance Ambient Air Duct Ψ	W/(mK)	0.166	Calculation see Secondary Calculation	
Length Ambient Air Duct	m	1.1		
Transmittance Exhaust Air Duct Ψ	W/(mK)	0.228	Calculation see Secondary Calculation	
Length Exhaust Air Duct	m	1.5		
Temperature of Mechanical Services Room	°C	11	Room Temperature (°C)	20
(Enter only if the central unit is outside of the thermal envelope.)			Av. Ambient Temp. Heating P. (°C)	4.0
			Av. Ground Temp (°C)	10.0
Effective Heat Recovery Efficiency $\eta_{HR,eff}$		82.0%		

Effective Heat Recovery Efficiency Subsoil Heat Exchanger

SHX Efficiency η_{SHX}	93%
Heat Recovery Efficiency SHX η_{SHX}	35%

Figure 98- Typical Ventilation Sheet (Passivhaus Institut 2007)

Passive House Planning

S U M M E R

Climate: **Standard Germany**
Building: **End-of-Terrace Passive House Kranichstein**
Location: **Darmstadt Kranichstein**

Interior Temperature: **20** °C
Building Type/Use: **Terraced House/Dwelling**
Treated Floor Area A_{TFA}: **156.0** m²

Spec. Capacity: **204** Wh/K pro m² TFA
Overheating Limit: **25** °C

Building Element	Temperature Zone	Area m²	U-Value W/(m²K)	Red. Factor f _{T,Summer}	H _{Summer} Heat Conductance
1. Exterior Wall - Ambient	A	184.3	0.138	1.00	25.3
2. Exterior Wall - Ground	B			1.00	
3. Roof/Ceiling - Ambient	A	83.4	0.108	1.00	9.0
4. Floor Slab	B	80.9	0.131	1.00	10.6
5.	A			1.00	
6.	A			1.00	
7.	X			0.75	
8. Windows	A	43.5	0.777	1.00	33.8
9. Exterior Door	A			1.00	
10. Exterior TB (length/m)	A	116.9	-0.030	1.00	-3.5
11. Perimeter TB (length/m)	P			1.00	
12. Ground TB (length/m)	B	11.4	0.061	1.00	0.7

Exterior Thermal Transmittance, H_{T,e} **64.6** W/K
Ground Thermal Transmittance, H_{T,g} **11.3** W/K

Heat Recovery Efficiency η_{HR} **82%** Effective Air Volume V_v **156.0** m² * Clear Room Height **2.50** m = **390** m³
SHX Efficiency η^{*}_{SHX} **93%**

Summer Ventilation

continuous ventilation to provide sufficient indoor air quality

Air Change Rate by Natural (Windows & Leakages) or Exhaust-Only Mechanical Ventilation, Summer: **0.23** 1/h

Mechanical Ventilation Summer: **1** 1/h with HR (check if applicable)

Energetically Effective Airchange Rate n_v **0.232** + **0.000** * (1 - **0.000**) + **0.000** = **0.232** 1/h
V_v m³ **390** * n_{v,equi,fraction} 1/h **0.232** * C_{Air} Wh/(m²K) **0.33** = **29.9** W/K
Ventilation Transm. Ambient H_{V,e} **390** * **0.000** * **0.33** = **0.0** W/K
Ventilation Transm. Ground H_{V,g} **390** * **0.000** * **0.33** = **0.0** W/K

Additional Summer Ventilation for Cooling

Temperature Amplitude Summer **11.7** K

Select: ☒ Window Night Ventilation, Manual
☐ Mechanical, Automatically Controlled Ventilation

Corresponding Air Change Rate **0.09** 1/h (for window ventilation: at 1 K temperature difference indoor - outdoor)

Minimum Acceptable Indoor Temperature **22.0** °C

Orientation of the Area	Angle Factor Summer	Shading Factor Summer	Dirt	g-Value (perp. radiation)	Area m²	Portion of Glazing	Aperture m²
1. North	0.9	0.92	0.95	0.50	11.0	64%	2.8
2. East	0.9	1.00	0.95	0.00	0.0	0%	0.0
3. South	0.9	0.40	0.95	0.50	30.4	65%	3.4
4. West	0.9	0.94	0.95	0.50	2.0	60%	0.5
5. Horizontal	0.9	1.00	0.95	0.00	0.0	0%	0.0
6. Sum Opaque Areas							1.1

Solar Aperture Total **7.8** m²/m² **0.05**

Internal Heat Gains Q_i Specif. Power q_i **2.10** W/m² * A_{TFA} **156** m² = **328** W **2.1** W/m²

Frequency of Overheating h_{θ ≥ θ_{max}} **3.2%** at the overheating limit θ_{max} = 25 °C
If the "frequency over 25°C" exceeds 10%, additional measures to protect against summer heat waves are necessary.

Daily Temperature Swing due to Solar Load **30.9** kWh/d * 1000 1/K / (**204** Wh/(m²K) * **156** m²) = **1.0** K

Figure 99- Typical Summer Sheet (Passivhaus Institut 2007)

6.2.2. Climate Data Input Sheets

The nine Scottish BRE weather data sets are specifically designed to be entered into PHPP with no formatting (BRE 2011b). This climate data is checked and ratified by the Passivhaus institute and can be used as data to certify Passivhaus designs (Mead & Brylewski 2012). Detailed analysis of the climate data reveals that it generates a milder climate than the data provided with PHPP for similar areas. More specific climate data is available from the BRE for specific sites to consider local micro climates. Similar specific data can also be extracted from Meteonorm software which requires re formatting. For this research, the nine climate datasets from BRE will be used. The PHPP requires the following 17 data categories;

- Latitude (°) & Longitude (°)
- Altitude
- Daily Temperature Swing Summer (K)
- Radiation Data: kWh/(m²*month)
- Heating Load 1
- Heating Load 2
- Cooling Load
- Ambient Temp
- Solar Insolation North
- Solar Insolation East
- Solar Insolation South
- Solar Insolation West
- Solar Insolation Global
- Dew Point
- Sky Temp
- Ground Temperature

The BRE data is discussed in more detail in section 6.4.1.

The following section explains the effect key components to the climate data used by PHPP to produce the results in the context of this study.

PHPP Climate Data Sheet

[Figure 100]

The climate data input sheet allows the specification of PHPP climate data and the input of custom climate data from the BRE and Meteonorm (for site specific information).

Passive House Planning

CLIMATE DATA

Standard/Regional Climate: Select here.

Regional Climate Data

Select Region Here

User Data

Select regional climate here:

West Scotland 15

Building:

4 Bed 2 Story

Use Regional Data?

Yes

Climate Building

West Scotland 15

Chosen Method for Annual Heat Demand: Monthly Method

Monthly Data:

West Scotland 15

Annual Data:

Use Annual Climate Data Set

No

Results:

Annual Heat Demand

14.0 kWh/(m²a)

Heat Load

9.2 W/m²

Parameters for PHPP Calculated Ground Temperatures:

Phase Shift Months

2.00

Damping

-1.05

Depth m

3.32

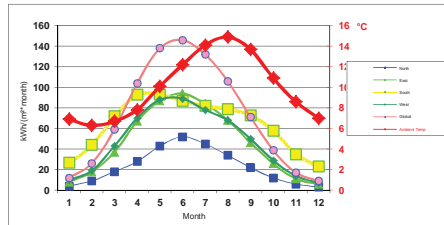
Shift of Average Temperature K

1.60

Month	1	2	3	4	5	6
Days	31	28	31	30	31	30
West Scotland 15	Latitude:	56.5	Longitude ° East	-5.4	Altitude m	3
Ambient Temp	6.9	6.3	6.7	7.8	10.1	12.2
North	4	9	18	28	43	52
East	8	18	37	67	87	94
South	27	44	72	93	93	89
West	10	19	43	70	88	146
Global	12	26	59	104	138	146
Dew Point	3.0	2.3	3.4	4.4	6.9	9.2
Sky Temp	-3.1	-4.2	-3.3	-2.9	-0.2	2.4
Ground Temp	11.6	11.2	11.2	11.7	12.5	13.4

Transfer to Annual Method

H _T	205	d/a
G _i	61	kKh/a
North	71	kWh/(m²a)
East	151	kWh/(m²a)
South	322	kWh/(m²a)
West	169	kWh/(m²a)
Horizontal	232	kWh/(m²a)



7	8	9	10	11	12	Heating Load		Cooling Load
31	31	30	31	30	31	Weather 1	Weather 2	Radiation
	Daily Temperature Swing Summer (K)			Radiation Data: kWh/(m²*month)		Radiation: W/m²		W/m²
14.1	14.9	13.7	10.9	8.6	7.0	1.5	3.5	16.9
45	34	22	12	6	3	4	4	39
84	68	46	26	11	6	9	5	71
82	79	73	58	35	23	41	17	99
78	68	50	29	14	7	11	7	79
132	106	71	39	17	9	12	9	128
11.1	11.9	10.4	7.4	5.1	3.2	3d	3d	3d
5.3	6.3	4.9	1.8	-1.0	-3.2			4.0
14.1	14.6	14.5	14.0	13.2	12.4	11.2	11.2	15.6

Figure 100- Climate Data Sheet (Passivhaus Institut 2007)

	Transfer to Annual Method	
H _T	205	d/a
G _i	69	kKh/a
North	77	kWh/(m²a)
East	173	kWh/(m²a)
South	386	kWh/(m²a)
West	190	kWh/(m²a)
Horizontal	251	kWh/(m²a)

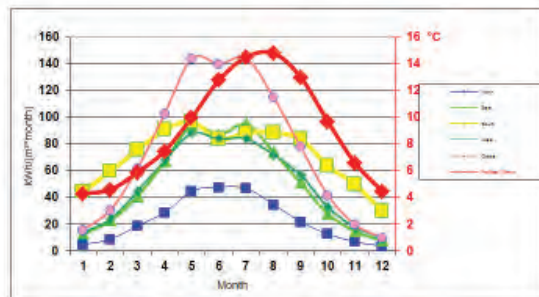


Figure 101- Typical Climatic Summary (Passivhaus Institut 2007)

6.2.2.1. Explanation of Weather Data and effect on Studies

A brief study determined the effects of the various climate data inputs.

The following data entries have a significant impact on the SSHD and heat load results:

- Latitude (°) & Longitude (°) Exact Position of Climate data on the Globe, effects solar angle, thus solar heat gains.
- Solar Insolation, Monthly Averages;
- North, South, East, West, Global (Non directional)(kWh/(m²*month))- Has a major effect on the building performance as this data controls the available solar gain. This data is compiled to generate the solar insolation values.
- Ambient Temperature, Monthly Averages (°C)- Has a significant effect on the heating requirements of the building. This data is compiled to generate the Gt value
- Ground Temperature, Monthly Averages (°C)- Effects the heat losses through the ground, e.g. ground floor slabs.
- Heating Loads- (Cold Clear, Overcast Warm)-The two sets of heating load figures represent the coldest, clear day and an overcast cold day, the PHPP uses the harshest result as the heating load figure.
- Cooling Loads

The following data entries have little or no effect on study results:

- Altitude
- Further user input for site-specific altitude- Only has an effect on results if user input is specified
- Dew Point (°C):
- Sky Temperature (°C)
- Summer Temperature Swing

6.2.2.2. PHPP Generated Weather Data Summaries for Annual Method

[Figure 101]

These inputs display the climate severity and totals for solar irradiation at a glance. These summaries are used for the annual heat demand calculations within PHPP. The monthly method uses the full climate data sets.

- Gt Values (Heating Degree Hours per annum (kKh/a)), detailed climate severity figure determining the number of degrees below 15.5°C per hour per annum
- Ht Value (Heating Days per annum (d/a)) Days that require heating (>15.5°C), provides an estimate on the heating season length in days.
- Solar insolation totals (kWh/(m²a) for North, South, East, West and Horizontal surfaces.

Passive House Planning

SPECIFIC ANNUAL HEAT DEMAND MONTHLY METHOD

(This page displays the sums of the monthly method over the heating period)

Climate: **West Scotland 15** Interior Temperature: **20** °C
 Building: **4 Bed 2 Story** Building Type/Use: **Semi Detached Rectangular 2**
 Location: **Scotland** Treated Floor Area A_{TFA} : **102.9** m²
 Spec. Capacity: **60** Wh/(m²K) (Enter in "Summer" worksheet.)

Building Element	Temperature Zone	Area m ²	U-Value W/(m ² K)	Month. Red. Fac.	G_i kWh/a	kWh/a	per m ² Treated Floor Area
1. Exterior Wall - Ambient	A	141.3	0.091	1.00	88	1132	
2. Exterior Wall - Ground	B			1.00			
3. Roof/Ceiling - Ambient	A	182.3	0.091	1.00	88	1459	
4. Floor Slab	B	128.7	0.151	1.00	62	1212	
5.	A			1.00			
6.	A			1.00			
7.	X			0.75			
8. Windows	A	25.4	0.825	1.00	88	1846	
9. Exterior Door	A	1.9	0.810	1.00	88	135	
10. Exterior TB (length/m)	A			1.00			
11. Perimeter TB (length/m)	P			1.00			
12. Ground TB (length/m)	B			1.00			

Transmission Heat Losses Q_T Total **5784** kWh/(m²a) **56.2**

Effective Air Volume V_{RAX} A_{TFA} **103** m² * Clear Room Height **2.50** m = **257** m³

Effective Air Change Rate Ambient $n_{v,a}$ **0.300** 1/h * η_{SHX} **0%** * η_{HR} **0.91** = **0.070** 1/h
 Effective Air Change Rate Ground $n_{v,g}$ **0.300** 1/h * η_{SHX} **0%** * η_{HR} **0.91** = **0.000** 1/h

Ventilation Losses Ambient $Q_{V,a}$ V_{RAX} **257** m³ * $n_{v,a}$ **0.070** 1/h * C_{Air} **0.33** Wh/(m²K) * G_i **88** kWh/a = **526** kWh/a **5.1** kWh/(m²a)
Ventilation Losses Ground $Q_{V,g}$ V_{RAX} **257** m³ * $n_{v,g}$ **0.000** 1/h * C_{Air} **0.33** Wh/(m²K) * G_i **62** kWh/a = **0** kWh/a **0.0** kWh/(m²a)

Ventilation Heat Losses Q_V Total **526** kWh/a **5.1** kWh/(m²a)

Total Heat Losses Q_L (Q_T **5784** kWh/a + Q_V **526** kWh/a) * Reduction Factor Night/Weekend Saving **1.0** = **6310** kWh/a **61.3** kWh/(m²a)

Orientation of the Area Reduction Factor g-Value Area Global Radiation
 See Windows worksheet (perp. radiation)

1. North	0.39	0.52	4.5	276	248
2. East	0.33	0.52	1.6	552	151
3. South	0.62	0.52	18.6	766	4564
4. West	0.33	0.52	0.8	565	77
5. Horizontal	0.40	0.00	0.0	859	0
6. Sum Opaque Areas					0

Available Solar Heat Gains Q_S Total **5040** kWh/a **49.0** kWh/(m²a)

Internal Heat Gains Q_I Length Heat. Period **0.024** d/a * Spec. Power q_i **2.1** W/m² * A_{TFA} **102.9** m² = **1894** kWh/a **18.4** kWh/(m²a)

Free Heat Q_F Q_S + Q_I = **6933** kWh/a **67.4** kWh/(m²a)
 Ratio Free Heat to Losses Q_F / Q_L = **1.10**

Utilisation Factor Heat Gains η_G = **70%**

Heat Gains Q_G η_G * Q_F = **4872** kWh/a **47.3** kWh/(m²a)

Annual Heat Demand Q_H Q_L - Q_G = **1437** kWh/a **14** kWh/(m²a)

Limiting Value **15** kWh/(m²a) Requirement met? **Yes**

Figure 102a- Typical Monthly Method Calculation Sheet (Passivhaus Institut 2007)

6.2.3. Data calculation summaries

The majority of the detailed data generated by PHPP is described in the following four results pages. However for this research a series of customised result analysis worksheets have been developed in the master file, these are suited to the different studies. This allows the relevant selected data for the study to be compiled and accessed on a single sheet. It allows for the detailed analysis of the prototype or a comparative analysis of simplified data between climatic regions.

Verification (Detailed in input section)

The PHPP front page which displays key results, including Specific Heat Demand (SSHD) and Heat Load (HL). Along with Primary Energy, Overheating and Cooling etc.

Annual Heat Demand

Calculates Specific Annual Heat Demand (SSHD), Standard Method

- Transmission Heat Losses (Building envelope losses)
- Ventilation Heat Losses
- Solar Heat Gains
- Internal Heat Gains
- Total Heat Gains
- Annual Heat Demand

Monthly Method

[Figure 102a/b].

Calculates Specific Annual Heat Demand, Monthly Method. The monthly method produces a more accurate figure than the Annual Heat demand, calculating figures per month rather than an annual average. This sheet displays a number of calculations that allow you to trace back though the SSHD calculation in detail.

As Annual Heat Demand with per month analysis of:

- Heating Degree Hours
- Losses
- Solar Gains
- Internal Heat Gains
- Sum Specific Solar Gains
- Utilisation Factor
- Specific Space Heating Demand

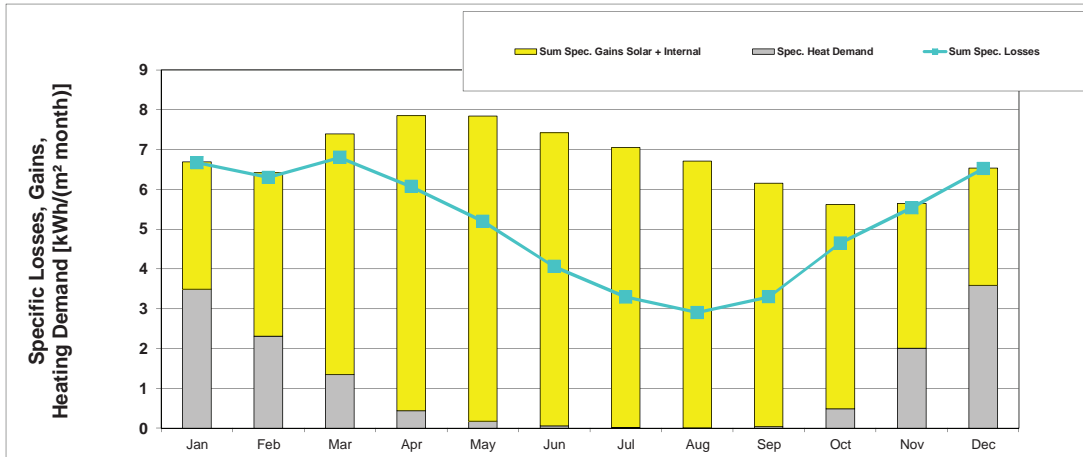
PASSIVE HOUSE PLANNING

SPECIFIC ANNUAL HEAT DEMAND

MONTHLY METHOD

Climate:	West Scotland 15	Interior Temperature:	20	°C
Building:	4 Bed 2 Storey	Building Type/Use:	Semi Detached Rectangular 2 Storey Soc	
Location:	Scotland	Treated Floor Area A _{TFA} :	103	m²

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year	
Heating Degree Hours - Ex	9.7	9.2	9.9	8.8	7.4	5.6	4.4	3.8	4.5	6.8	8.2	9.7	88	kKh
Heating Degree Hours - G	6.2	5.9	6.5	6.0	5.6	4.8	4.4	4.1	4.0	4.4	4.9	5.7	62	kKh
Losses - Exterior	565	533	573	509	427	325	254	220	263	392	476	560	5098	kWh
Losses - Ground	121	115	127	116	108	92	85	79	77	86	95	111	1212	kWh
Sum Spec. Losses	6.7	6.3	6.8	6.1	5.2	4.1	3.3	2.9	3.3	4.6	5.5	6.5	61.3	kWh/m²
Solar Gains - North	4	8	16	25	39	47	40	31	20	11	5	3	248	kWh
Solar Gains - East	2	5	10	18	24	26	23	19	13	7	3	2	151	kWh
Solar Gains - South	161	262	429	554	554	518	489	471	435	346	209	137	4564	kWh
Solar Gains - West	1	3	6	10	12	12	11	9	7	4	2	1	77	kWh
Solar Gains - Horiz.	0	0	0	0	0	0	0	0	0	0	0	0	0	kWh
Solar Gains - Opaque	0	0	0	0	0	0	0	0	0	0	0	0	0	kWh
Internal Heat Gains	161	145	161	156	161	156	161	161	156	161	156	161	1894	kWh
Sum Spec. Gains Solar + I	3.2	4.1	6.0	7.4	7.7	7.4	7.0	6.7	6.1	5.1	3.6	2.9	67.4	kWh/m²
Utilisation Factor	99%	97%	90%	76%	66%	54%	47%	43%	53%	81%	97%	100%	70%	
Annual Heat Demand	359	237	139	46	18	5	2	1	4	50	207	369	1437	kWh
Spec. Heat Demand	3.5	2.3	1.3	0.4	0.2	0.1	0.0	0.0	0.0	0.5	2.0	3.6	14.0	kWh/m²



Annual Heat Demand: Comparison

EN 13790 Monthly Method	1437	kWh/a	14.0	kWh/(m²a) Reference to habitable area
PHPP, Heating Period Method	1374	kWh/a	13.3	kWh/(m²a) Reference to habitable area

Month	1	2	3	4	5	6	7	8	9	10	11	12	Annual Total	Heating Period Method
Days	31	28	31	30	31	30	31	31	30	31	30	31	365	205
Ambient Temp.	6.90	6.30	6.70	7.80	10.10	12.20	14.10	14.90	13.70	10.90	8.60	7.00	10.0	7.6
North Radiation	4.0	9.0	18.0	28.0	43.0	52.0	45.0	34.0	22.0	12.0	6.0	3.0	276	71
East Radiation	8.0	18.0	37.0	67.0	87.0	94.0	84.0	68.0	46.0	26.0	11.0	6.0	552	151
South Radiation	27.0	44.0	72.0	93.0	93.0	87.0	82.0	79.0	73.0	58.0	35.0	23.0	766	322
West Radiation	10.0	19.0	43.0	70.0	88.0	89.0	78.0	68.0	50.0	29.0	14.0	7.0	565	169
Hori. Radiation	12.0	26.0	59.0	104.0	138.0	146.0	132.0	106.0	71.0	39.0	17.0	9.0	859	232
Tsky	-3.10	-4.20	-3.30	-2.90	-0.20	2.40	5.30	6.30	4.90	1.80	-1.00	-3.20	0.3	
Ground Temp	11.60	11.19	11.24	11.72	12.51	13.40	14.14	14.55	14.51	14.03	13.24	12.35	12.9	12.1

Figure 102b- Typical Monthly Method Calculation Sheet (Passivhaus Institut 2007)

Heating Load

- Transmission Heat Losses (Building envelope losses)
- Ventilation Heat Losses
- Ventilation Heat Load
- Total Heating Load
- Heating Load Transportable by Supply Air

Inputs Areas

Title of Study

Floor	107
North Wall	61.36
South Wall	61.36
East Wall	43.05
West Wall	43.05
Floor Slab	69.6
Roof	89.7
Parti Wall Roof WEST	0
Parti Wall Roof EAST	0

UK Average Climate

Specific Space Heat Demand, 13.605

Orkney 20

Specific Space Heat Demand, 22.171

West Scotland 15

Specific Space Heat Demand, 12.760

East Scotland 16

Specific Space Heat Demand, 13.496

Windows

	Width	Height	No	Dev Nrth	Area	Area	% Area of Surface
North Windows	1	1.9	2	1	North=1	0	3.8
	2		0	1		0	6.19%
East Windows			0	3	East=3	90	0
	2		0	3		90	0.00%
South Windows	1.25	1.9	8	2	South=2	180	19
	2	1.2	5	2		180	11.4
							49.54%
West Windows			0	4	West=4	270	0
	2		0	4		270	0.00%
Horizontal Windows			0	6	Roof=6	0	0
Door	1.1	2.25				0	0

Watch for Parti Area

Volumes

Enclosed (Gross Volume)	507.99	East x Length	507.99
Ventilation Volume		Length	11.8

Done

Occupants

Occupants	4
-----------	---

0.14
0.14
0.15

Ventilation

Summer Ventilation

Air Change by Natural	1.49
Night Ventilation	1.49
Mechanical	0.3

U-Values

Thickness		
Walls	0.117	34.1
Roof	0.117	34.1
Ground	0.181	27.6
g-Value Ug- Value		
Glazing	0.52	0.61
Y-Spacer Uf- Value Y Installation		
Frame	0.043	0.63
	0.04	

Original Inputs

0.117	34.1
0.117	34.1
0.181	27.6
g-Value	Ug- Value
0.52	0.61
Y-Spacer	Uf- Value
0.043	0.63
Y Installation	0.04

Inputs for South Facing 15 kWh/(m2a)

Orkney	West	East
0.092	0.158	0.151

Ground

Insulation W/D	0.71
Thickness	0.1
Thermal Conductivity	0.02 W/(mk)

Input for Ventilation Climate 16

PH CSH
0.6 Ach 1.3 Ach
0.14 w/m2 0.14 w/m2

Shading

	South	East+West	North	Horizontal
Reveal Depth	0.2	0.2	0.2	0.1
Glaze to Reveal	0.05	0.05	0.05	0.195
Overhang	0.2	0.2	0.2	0.15
Glaze to Overhang	0.05	0.05	0.05	0.05
Add	100%	100%	100%	100%
Summer Shading (0 total)	50%			

Figure 103- Customised Input Sheet with Typical Values for 107m2 housing prototype

6.2.4. Custom Data Input Sheet

As described in the Methodology Chapter section 5.6 a customised Excel customised data input file and worksheet was developed for the research. An overview of the typical simplified data entries are given below for the typical detached prototype detailed in section 6.4: [Figure 103]

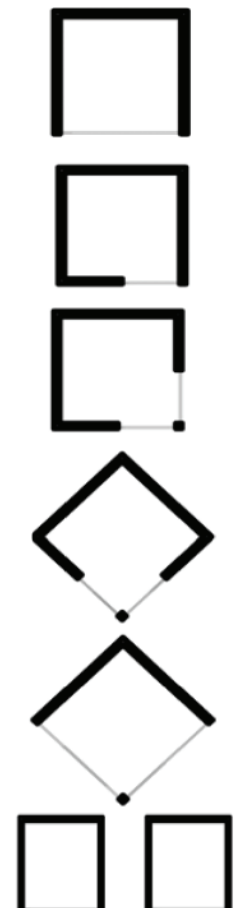
6.3.Study 0- 50m² Studio

A preliminary study using a small 50m² building quantifies the effects on SSHD and overheating due to changing orientation of the volume from due south. The aim is to establish the viability of possible window design variations to compensate for a change in orientation using a south facing prototype with 50% glazing to the south, a recognised starting point for low energy housing. The study uses a 50m² single volume, however due to its small scale is more sensitive to small changes due to its small area and relatively high surface to area ratio. The study was performed using an unaltered PHPP calculation file, therefore simultaneous comparison of different building data required a file for each design. Due to this, a customised linked results page was developed that allowed for easier comparison of the different design options. This study demonstrated the requirement for the PHPP master file and changes to the original PHPP methodology.

Study Variables

The glazing percentage is based on the internal measurement rather than the external measurement.

- South orientation (1)
21m² 50% glazing across the south facing façade with no other openings. This was determined from best practice for solar gain SSHD reduction.
- South Orientation 25% (2)
10.5m² 25% glazing across the south facing façade with no other openings.
- South Orientation Corner Glazing (3)
This model re distributes the full 21m² glazing to 10.5m² on the south and 10.5m² to the east
- 45° Deviation from South orientation (4)
This model uses the previous 21m² corner glazing, rotated 45° to for glazing to face south east and south west.



- 45° Deviation from South orientation
Increased Glazing (5)
The area of glass is increases to have a full 21m² to the south east and south west.
- Two Storey South Orientation (6)
This model retains the 21m² 50% glazing across the south elevation, but the floor area is divided into two equal storeys.

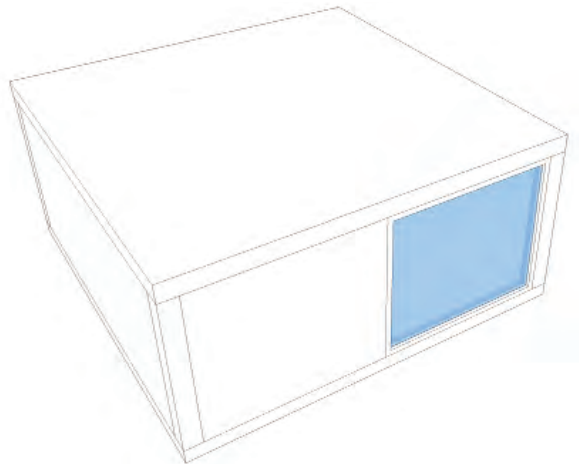


Figure 104- 50m² Model (1) Representation

Inputs (Type (1)):

[Figure 104]

- Floor Area- 50m²
- Floor Slab- 59m²
- Wall Area- 90.2m²
- Roof Area- 59m²
- Window Area- 21m²
- Door 2.4 m²
- MVHR: Paul Novous 300
- Airtightness 0.6 1/h

U-Values

- Roof: 0.117 W/(m²K)
- Walls: 0.117 W/(m²K)
- Floor: 0.181 W/(m²K)
- Door: 0.8 W/(m²K)
- Door: 0.8 W/(m²K)
- Average for Windows: 0.78 W/(m²K)
- Average Overall: 0.2 W/(m²K)

Climate Data

The study was based in East of Scotland Climate which highest solar insolation values of the Scottish regional climate data range to allow for maximum sensitivity for overheating.

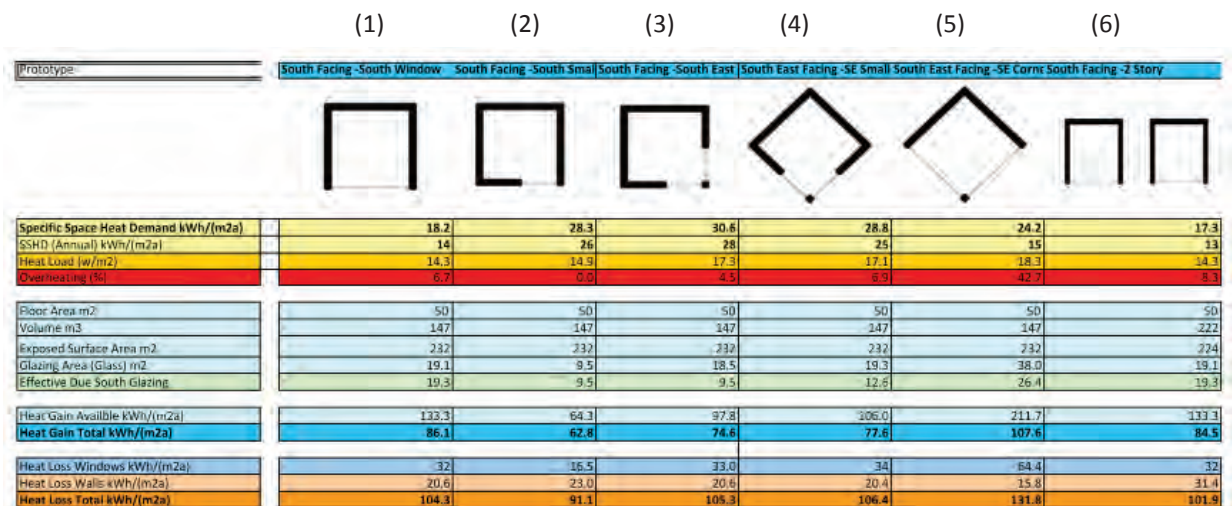


Figure 105- 50m² Results

Results and Analysis

[Figure 105].

The initial model was a single storey square plan (1) with 50% glazing obtained a 18.2 kWh/(m²a) SSHD and showed slight overheating. This figure SSHD increases by 10 kWh/(m²a) with a 50% reduction in glazing (2), but illustrates no overheating. The addition of corner glazing to the east elevation (3) raises the SSHD by 2.3 kWh/(m²a) to 30.6 kWh/(m²a) due the lack of useful solar gain and increased losses. Rotating the form 45 degrees with 25% (4) and 50% (5) glazing to the south east and south west facades demonstrates an increase in the SSHD from the initial prototype (1) to 28 kWh/(m²a) and 24 kWh/(m²a). The prototype with the largest amount of glazing (5) results in significant overheating at 43%. The final study explored a double storey type with 50% glazing (6) which has the lowest SSHD of all types with a 0.9 kWh/(m²a) reduction on the initial prototype. The study illustrates that both the reduction in glazing (from 50% to 25% of the façade), the alteration of orientation with attempts at compensatory variations in glazing does not increase performance SSHD from a south facing design with 50% glazing (1) and often leads to greater overheating (4)(5). The increase of east facing glazing only slightly contributes to the SSHD but tends to cause overheating. The only study that did not produce overheating was the due south facing study with 25% glazing (2), however this also demonstrated one of the highest SSHDs. The only prototype with better SSHD performance and similar overheating was the double storey variant (6). The reduction in SSHD with the two storey model (6) is due to the lower heat losses through the external envelope. The exposed surface area of the standard model is 232m², the double storey reduces to 224m² due to the more efficient form factor. The study confirms the best practice guidance of 50% south facing glazing is suitable in the Scottish climate. The performance increase from a more efficient two story form factor was also confirmed. The results highlight the requirement for solar shading and a reduction in east facing glazing for balanced SSHD and overheating in the East of Scotland climate.

6.4. Study 1- Housing prototype- Design Specification & Effects of Climatic Variation on SSHD

Housing prototype design methodology and technical specification

A control prototype is used to test a range of changes in the following studies including, climate, orientation glazing design and building form to understand how these affect SSHD in the different climate data regions. The prototype was developed using the PHPP 'Dolls House' methodology and is representative of a standard mass market 3-4 bedroom house with 107m² TFA [Figure 106]. The floor area of the house reflects kit house sizes popular in Scottish mass market housing found in rural areas and is similar to the UK average for a four bed, six person two storey house which is 110m² (BRE & Clones 2009; St. Andrew's House Scottish Government 2011a; Scotframe 2011). The 3m² discrepancy takes into consideration the variance in area measuring methodologies between the standard UK methodology and the German methodology used to calculate treated floor area. It is designed around the Passivhaus Doll's house principles and is not intended to be a functional/formal architectural design. The Doll's house method is used in the Passivhaus Designers course in order to demonstrate the student's working knowledge of the Passivhaus principles. This is a house designed to comply with the standard in the simplest way possible. Based on typical passive solar principles the house has around 50% south facing glazing and minimal northern openings (Edwards 2010; Intelligent Energy Europe 2011). Specifically, the house utilises passive solar gain principles with 11.4m² (50%) glazing on the principle south elevation. It has minimal glazing on the north elevation (~6%), the utility and service areas are to the north elevation to allow for maximum south glazing and solar heat gain. The utility and service areas were zoned to the north of the plan in order to maximise solar exposure to the open plan living space and principle rooms to the south. The south elevation is around twice the length of the end elevations creating a large area of southern glazing to allow solar heat gain into the principle rooms. The planning and sectional arrangements are comparatively simple, providing enough flexibility to allow the plan to be reconfigured to the three different typologies tested. The prototype demonstrates simple spatial characteristics such as; large open plan living space, no double height volumes creating an efficient surface to volume ratio (0.74 detached, 0.65 semi-detached, 0.56 terraced). The double pitch roofing form does not create the optimal surface area, but this form is typical of the majority of Scottish housing. It is also suitable for the addition of energy generating solar panel systems although, these are not specified in this research. The fabric specification is derived from current Passivhaus built examples in Scotland and tested through PHPP to achieve a balance of building fabric specifications that are viable for construction in Scotland. The house is specified with a Passivhaus certified Mechanical Recovery Ventilation Unit (MVHR)(90% efficient) to reduce the heating lost through natural ventilation in winter which in most cases is a requirement for Passivhaus certification. The original prototype specification is designed and specified to meet the Passivhaus criteria of 10w/m² heating load and Specific Space Heat Demand of less than 15 kWh/(m²a), using the BREs West of Scotland and East of Scotland climate data. The specification used allows additional climates (North East Scotland & NW England\ SW Scotland) to meet the Specific Space Heat Demand of 15 kWh/(m²a). This has generated the fabric specification, which is constant throughout the initial thermal analysis studies. Later studies use a weighted u-value method for comparative analysis.

'Dolls House' Prototype 107m²

Specification

3-4 bedroom, prototype house with 107m² TFA, specification meets PH certification criteria of 10w/m² heating load and Specific Space Heat Demand of less than 15 kWh/(m²a), using the BRE's "West of Scotland" and "East of Scotland" climate data.

50% South Glazing (30.4m²)

Minimal North Glazing ~6%

90% Efficient MVHR Unit

U-Values

Roof: 0.117 W/(m²K)

Walls: 0.117 W/(m²K)

Floor: 0.151 W/(m²K)

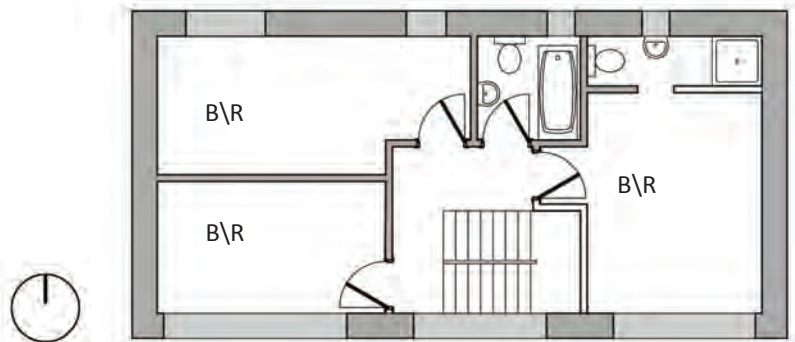
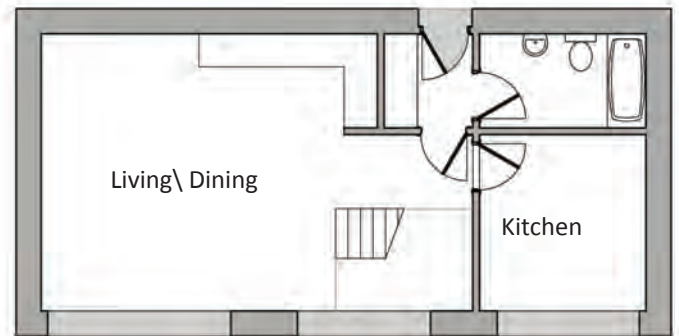
Surface\ Volume: 0.73

Exposed Surface Area: 317m²

Average U-Values:

Average for Windows: 0.82 W/(m²K)

Average for thermal envelope:
0.2 W/(m²K)



Prototype Energy Balance for East of Scotland

Specific Space Heat Demand (Monthly)

11.08 kWh/(m²a)

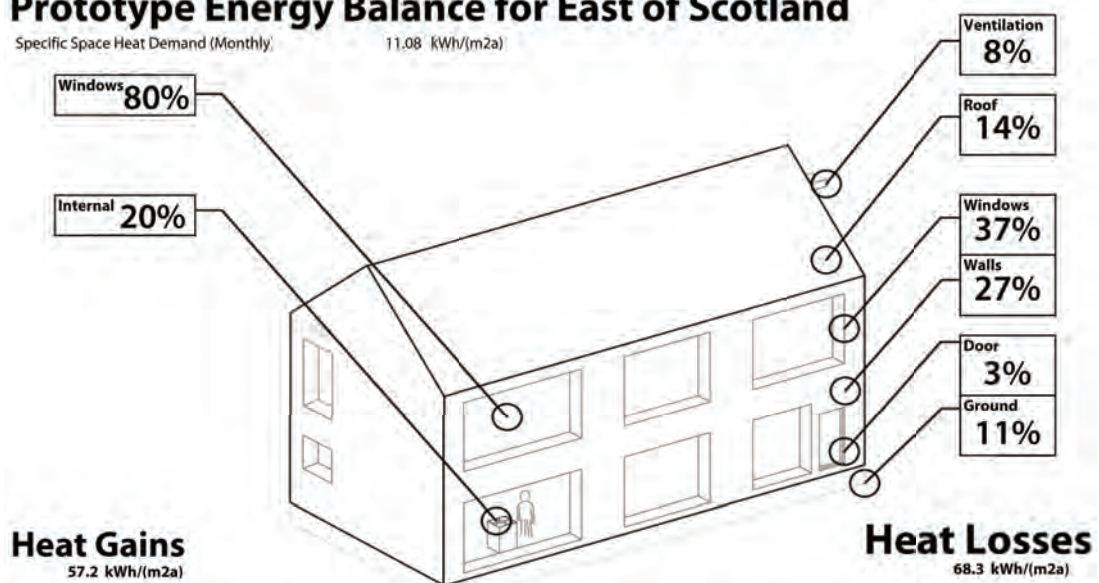


Figure 106- Housing Prototype Details and Drawings

U-Values;

- Roof: 0.117 W/(m²K)
- Walls: 0.117 W/(m²K)
- Floor: 0.151 W/(m²K)
- Average for Windows: 0.82 W/(m²K)
- Average for thermal envelope (detached model): 0.2 W/(m²K)

The immediate site is assumed to be flat with no over-shading from trees or other buildings. This allows all solar gains available to the site to be utilised. Due to the large amount of solar heat gain, shading is required on the south façade. Seasonal shading such as blinds, which block 50% of the solar heat gain to the south elevation when required are specified. This figure was determined by defining a maximum temperature swing of less than 3 Kelvin, this figure relates to thermal comfort and results in no overheating when combined with adequate ventilation in Scottish climates. The window reveal depth was fixed at 0.2m and the overhang depth was also fixed at 0.2m for all studies.

The MVHR is assumed to be Passivhaus certified Paul Novus 300DC with an efficiency rate of ~90% (PHPP generated), which is constant through all studies unless otherwise stated. All aspects of the housing design and specification comply or exceed 2010 Scottish Building Warrant Standards (Scottish Government 2008a). There are a series of Technical Omissions that were deemed to be outwith the requirements of the comparative study. Modelling of thermal bridging was beyond the scope of this study and an assumption was made that the construction would be thermal bridge free, no psi-value (Ψ) input. The heating system fuel, energy details and domestic hot water details were omitted, as they do not significantly affect the thermal properties of the prototype. The information regarding primary energy and electrical systems has also been omitted. Due to the study using the same base PHPP inputs, these omissions will not affect the comparative data.

6.4.1. Study 1A: BRE Scottish Regional Climate Study

This study will quantify the differences between the SSHD of the detached prototype across the different Scottish climatic regions illustrating the effects that different climates have on the heating performance of a ULEH. It is already known that climate is a significant factor in rural fuel poverty particularly in the remoter and often harsher Scottish climate regions such as the North of Scotland the Island areas. The following questions are investigated:

- To what extent does the climatic variation across Scotland effect the SSHD of ULEH?
- What are the extremes of SSHD performance of housing across Scotland?

This study requires the use of nine PHPP calculation Excel Spread sheet files each containing a single BRE Scottish regional climate dataset. These PHPP files have fixed information such as technical specifications for

glazing, MVHR and ventilation and are linked through the customised PHPP master file to receive the building metrics. They then output results back to the customised master file. This development of the PHPP input and output methodology is used for the remainder of the studies in the research.

Study Variables

Nine alternative Scottish Climate data sets (BRE 2011c):

- North West England SW Scotland 9
- Borders 10
- West Scotland 15
- East Scotland 16
- North East Scotland 17
- Highlands 18
- Western Isles 19
- Orkney 20
- Shetland 21

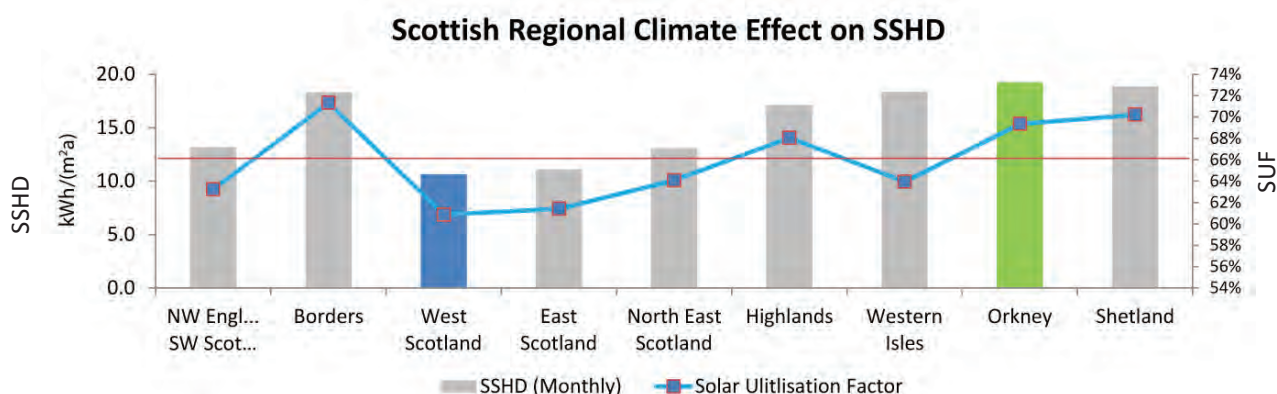


Figure 107- Scottish Regional Climate Effect on SSHD

Results

[Figure 107] Scottish Regional Climate Effect on SSHD

[Figure 108] Percentage Increase from West of Scotland

The results show a marked difference of 81% in SSHD between the lowest result in the West of Scotland (10.6 kWh/(m²a)) and the highest result in Orkney (19.2 kWh/(m²a)). This has effect on the SSHD will have a major effect on the cost of heating per annum due to the increased heading demand. This major difference between the extreme regions clearly illustrates the need for regional solutions to ultra-low energy housing. In most of the climates the Solar Utilisation Factor (SUF) is a

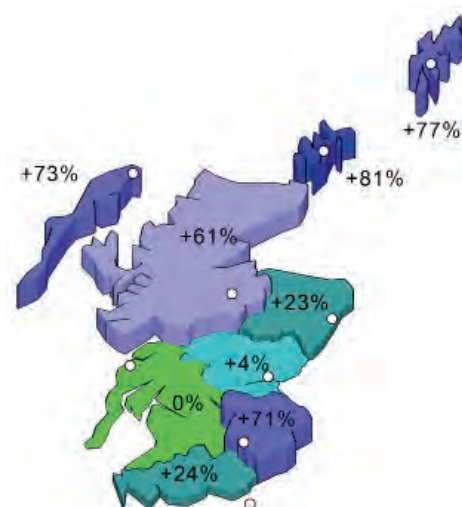


Figure 108- Percentage Increase from West of Scotland

key component in determining the percentage of usable solar heat gains for a given design performance specification in the given climate and generally reflects the trend of the SSHD. The Orkney and West of Scotland climate data regions were subsequently used for other research studies as they represent the extremes of the Scottish climate. It is clear from the increases from the lowest SSHD in the West of Scotland more rural areas of Scotland such as the North of Scotland, the Borders and the islands have significantly higher SSHD than the central belt that contains the majority of the urban centres. The results of this study suggest the requirement for a variation in required specification across different regions in Scotland in order to achieve an equal standard of ULEH performance across the regions.

6.4.2. Study 1B: Average UK Climate Study

The Scottish climate differs significantly from the rest of the UK. This study determines the difference in SSHD when using the BRE's UK average climate data versus specific regional Scottish climate data. SAP generates the predicted heating energy requirement and carbon emissions using BRE average UK climate data. The variation between SSHD when using the UK average climate data and regional Scottish climate data will provide the approximate variation in SAP's predicted SSHD and carbon emissions if it were to use region specific data. This will not provide an exact comparison as the input methodologies, input scope and heat gains differ between SAP and PHPP despite being based on the same calculation ISO-standard 13790 (Tuohy & Langdon 2009). The complexity of the climate data also differs, SAP uses the follow metrics:

- Wind Speed
- External Temperature
- Solar Radiation (Horizontal Only)
- Latitude

In contrast PHPP uses 17 categories of weather attributes described in 6.2.2. This generated average UK data will give the variation between the same regional climates used in SAP's average climate data in comparison to Scottish regional climate data sets. The UK average climate data for use in PHPP was prepared using a same mean average calculation as the UK average climate data used in SAP. The same 21 climatic regions are available for the PHPP and are used to create the SAP average (BRE 2011a, p.2012; BRE 2011c). It is difficult to establish if the quantitative data is the same as the two pieces of software use different data formats. However both the SAP data and PHPP data are produced by the BRE. This study answers the question:

- How do Scottish climates differ from the climate data used for UK ZCH legislation in terms of SSHD?

Study Variables

- Average UK Climate Data (Used in SAP)
- Orkney (Highest SSHD in Scotland)
- West of Scotland (Lowest SSHD in Scotland)

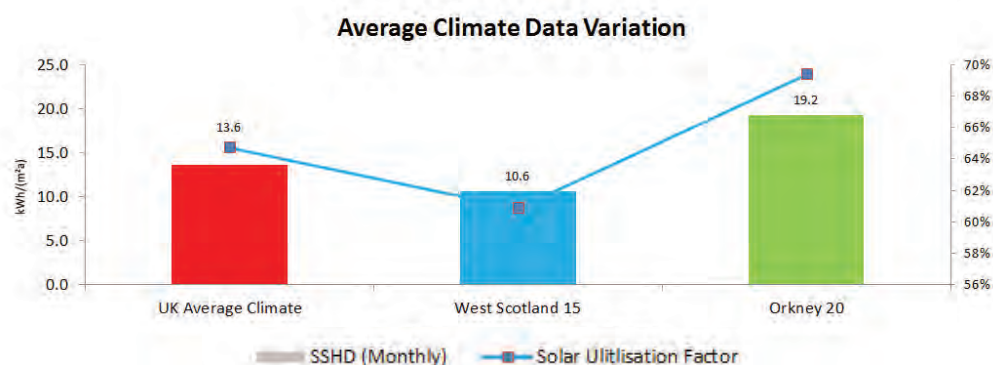


Figure 109 Scottish Extremes & Average Climate Data Variation

Results and Analysis

[Figure 109]

The results show a variation of 3 kWh/(m²a) in SSHD between the better performing West of Scotland and the UK average climate. This implies that the West of Scotland climate will perform around 22% better than the UK average. However the greatest variation is seen between the UK average climate and Orkney with a 5.6 kWh/(m²a) higher SSHD. This variation implies that Orkney will perform 29% worse in terms of SSHD performance than the UK average climate, therefore increasing space heating bills by the same magnitude. The UK average climate data achieves an SSHD of 13.6 kWh/(m²a), this figure is similar to the performance of the *North West England SW Scotland* region found in Study 1A.

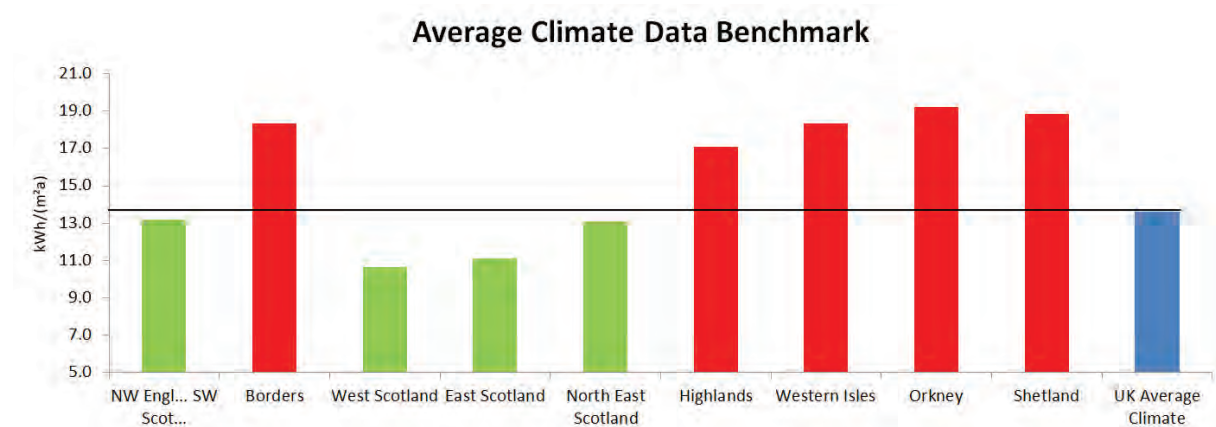


Figure 110- Average Climate Benchmark

Average Climate Comparison

[Figure 110]

A simple comparison is performed using the results from the previous *Scottish Climate Variation Study* (1A). The average climate data is representative of the UK's current thermal analysis methodology (SAP) therefore any Scottish regions performing worse than the UK average will have higher than estimated actual heating energy performance using this methodology. The comparison demonstrates that five (marked in red [Figure 111]) of the nine Scottish climates perform worse than the average climate data. The regions illustrated the

following increases from the 13.6 kWh/(m²a) UK Average;

- +4.7 kWh/(m²a) - Borders 10
- +4.8 kWh/(m²a) -Western Isles 19
- +3.5 kWh/(m²a) -Highlands 18
- +6.6 kWh/(m²a) -Orkney 20
- +5.3 kWh/(m²a) -Shetland 21

This infers that the EPCs generated through SAP for these parts of Scotland are inaccurate due to the lower than UK average climatic performance of these regions.. These climatic regions that perform worse than the UK average cover many of the rural areas in Scotland. The urban areas in the central belt generally have climates that perform better than the UK average. This illustrates the requirement for regional specific approaches, specifications and guidance for ULEH in rural Scotland.

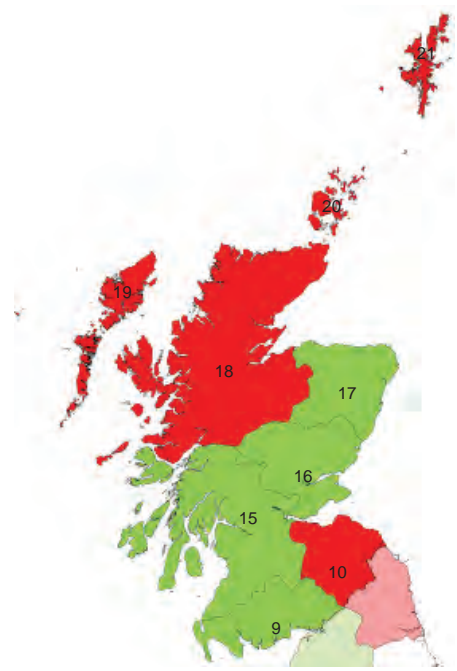


Figure 111- Regions with Higher SSHD than the UK average (red)

Weighted U-Values

The results of this study are used as a benchmark to generate thermal performance specifications that will allow the detached, semi-detached and mid terrace prototypes to achieve a SSHD of 15 kWh/(m²a) in each regions. The changes that are made to the thermal performance specification are achieved by modifying the roof and wall u-values. This demonstrates firstly, the impact of climate variation on the thermal specification of the prototype and secondly it shows the effect of aggregated housing types on the reduction of SSHD due to the lower number of external exposed surfaces available in these forms. These weighted u-values are to be used later in this chapter and in the later in Chapter 7. From the data generated in this study the following U-values are required for the detached prototype to achieve Passivhaus SSHD in each of the climates. An estimate in wall thickness is given using a timber frame construction and high-performance insulation.

- Orkney: 0.091 W/(m²K)- ~419mm
- East of Scotland: 0.149 W/(m²K)- ~280 mm
- West of Scotland: 0.157 W/(m²K)- ~270mm
- UK Average: 0.132 W/(m²K) –~310mm

The u-values are based on a typical timber construction using extruded closed cell polystyrene insulation and cladding. The variation between the West of Scotland and Orkney translates into a significant increase in fabric specification and construction build-up. This requires a greater thickness of insulation, increasing the wall thickness by 56% or 149mm when comparing West of Scotland's build-up.

The following weighted u-values are used for the semi-detached study in Chapter 7 to achieve 15 kWh/(m²a).

- Orkney 0.11 W/(m²K)
- East of Scotland is not used in this study.
- West 0.188 W/(m²K)
- UK Average 0.156 W/(m²K)

The following weighted u-values are used for the mid terrace study Chapter 7 to achieve 15 kWh/(m²a).

- Orkney 0.137 W/(m²K)
- East of Scotland is not used in this study.
- West 0.234 W/(m²K)
- UK Average 0.194 W/(m²K)

6.5. Study 2- Effects of Orientation and Building Form on SSHD

The following studies alter the orientation or building form of the prototype. The study outline is shown in [Figure 112]. The alterations all have a varying effect on the SSHD depending on the degree of deviation from best practice. All of the studies use the detached prototype with the exception of Study 2D, dwelling typology. All of the studies use the extremes of Scottish regional climate determined in Study 1A: Orkney generates the highest SSHD and West of Scotland the lowest. The orientation studies (2A, 2B) also use the East of Scotland climate due to the high levels of solar insolation in this climate.

Chapter 6- Study Structure






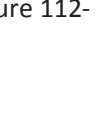

	Climatic Region	1A 1B	Section 6.4
	Orientation	2A 2B	6.5
	Roof Form	2C	
	Typology	2D	
	South Glazing	} 2E	
	North Glazing		
	Airtightness & MVHR	3A	6.6
	ZCH Specification	3B	

Figure 112- 2X Study Structure

6.5.1. Study 2A: Dwelling Orientation Study

It is well documented that orientation has an effect on the Specific Space Heat Demand (SSHD), this study quantifies its effect in the East of Scotland, West of Scotland and Orkney. The study answers the research question:

- To what extent does the orientation effect the SSHD across the extremes of the regional Scottish climates?

The variation of SSHD through 45° increments over 360° from north facing orientation is defined in this study and aims to define the range of viable deviation from south in the different climate regions in Scotland when trying to achieve ULEH SSHD. The prototype is designed to maximise passive solar gain, which works efficiently through reliance on significant solar heat gains from the south elevation. Orientation has a significant bearing on the siting of buildings and urban form, particularly in contexts where achieving a due south orientation would be difficult or constrained by topography or existing urban fabric. Generic UK design guidance is mixed. Guidance generated from experience with the Milton Keynes Pennyland and Great Linford solar urban planning studies recommended that orientating buildings $\pm 40^\circ$ from due south to take advantage of solar gains (Fuller et al. 1982, p.15). This previously accepted guidance is now less suitable for contemporary low energy housing due to greatly decreased heat losses and the increased reliance on solar heat gain for space heating contribution. Other contemporary guidance states that an orientation of $\pm 45^\circ$ from due south is favourable (Hastings & Wall 2007, p.p15). UK specific guidance for Passivhaus specifies a $\pm 30^\circ$ from due south as allowable variation for meeting the criteria (McLeod et al. 2011, p.2). This guidance states that a greater variation than this can increase the SSHD by 30-40%.

Study Variables

45° increments across 360°. Using PHPP this would require alterations to the *Windows Sheet*. All *Deviation from North* window orientation but, inputs in the PHPP are altered by the custom data input sheet. The customised data sheets allows for the window orientations to be changed simultaneously by simply entering the figure that the orientation needs to change by in a single cell as all of the PHPP inputs reference this cell.

- North
- North East
- East
- South East
- South
- South West
- West
- North West

Climate Data

- West Scotland
- East Scotland
- Orkney

Results and Analysis

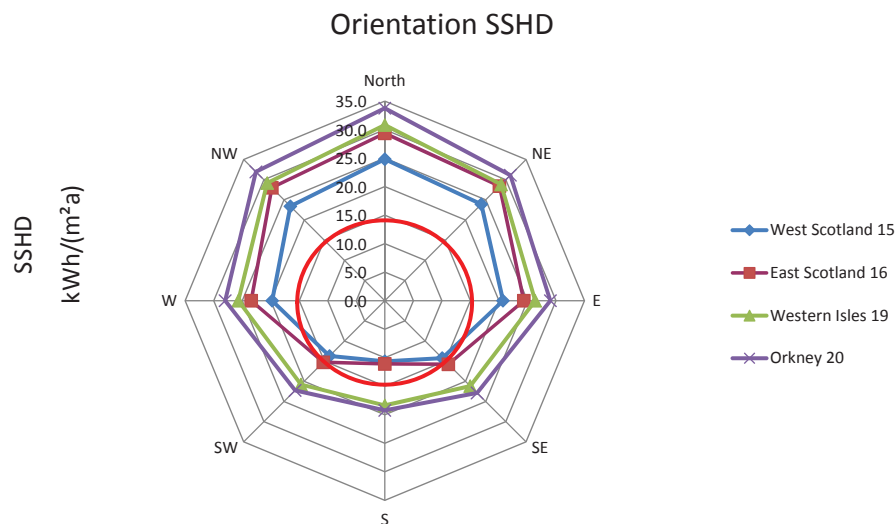


Figure 113- Orientation SSHD 360 Degrees

[Figure 113]

The results illustrate a significant increase in SSHD (42%-38%) at 45 degree variation from due south in the East of Scotland region. East of Scotland is shown to have the largest increase in the SSHD of 165% when the building is rotated 180° (11.08 kWh/(m²a) increases to 29.36 kWh/(m²a)). In the West of Scotland region there was a lesser increase of 29% (west) and 34% (east) from due south. Although the original value for Orkney exceeded the benchmark at 19.2kWh/(m²a), the percentage increase in SSHD at ±45° (16% (West) and 19% (East)) was considerably less than both the other climates which demonstrated increase of between 30-40%. This increase in SSHD corresponds to an equal increase in heating costs over a year. This is due to the significant reliance of solar gains in warmer, sunnier climates (East of Scotland, West of Scotland) in contrast to regions that are not heavily reliant on solar heat gains (Orkney).

Previous published research recommends orientations of between ±40-45° from due south to take advantage of solar gains is misleading. Much of this research was performed using simple techniques such as shadow prints using much lower performance building specifications in the 1980s (Fuller et al. 1982, p.15). Therefore with sophisticated computer simulation and higher performance building specification this previous research is outdated. Additionally the results show that the extent of solar gains available depends on the climatic conditions. In the Scottish climate an alteration of 45° has a more significant effect in some solar dependant climates when using ULEH building specification. The degree of alteration from due south and its effect on SSHD requires a higher resolution study. The study results highlights the need for a higher resolution to accurately define the variation between ±45° of due south due to the increases in SSHD around this orientation.

6.5.2. Study 2B: Orientation Fine Grain Analysis Study

A more detailed analysis of the effects of orientation on the SSHD of the prototype it uses 10° degree increments from due south to $\pm 40^\circ$ due south in addition to north, east and west. U-Values were weighted to determine the variations specific to the climatic region as defined in Study 1B. The study uses the u-values for achieving exactly 15 kWh/(m²a) at due south in the three selected climates. This clarifies the comparative deviation in kWh/(m²a) rather than only a percentage increase or decrease.

Study Variables

The prototype's window orientation was altered in the following increments using the same method as study 2A.

- North
- East
- South
- West
- $\pm 10^\circ$ due south
- $\pm 20^\circ$ due south
- $\pm 30^\circ$ due south
- $\pm 40^\circ$ due south
- $\pm 45^\circ$ due south

Climate Data

- Orkney
- West of Scotland
- East of Scotland
-

Weighted to achieve SSHD 15 kWh/(m²a) (Passivhaus) in Climate:

- Orkney: 0.091 W/(m²K)
- West of Scotland: 0.157 W/(m²K)
- East of Scotland: 0.149 W/(m²K)

Results and Analysis

[Figure 114]

Similarly to the previous study (2A) East of Scotland climate showed the greatest increases in SSHD with increasing deviation from due south. The results show a small increase in SSHD (<2%) when deviating 10° from due south and between a 5% and 7% increase with 20° deviation. At 30° deviation, the SSHD increase is around 12-15%. At 40° deviation, the heat demand increases by 22-25%. The West of Scotland and East of Scotland are more solar gain reliant (higher solar isolation levels) than the Orkney region (low solar isolation level) and are more sensitive to changes in orientation due to their reliance on solar gains. The alterations

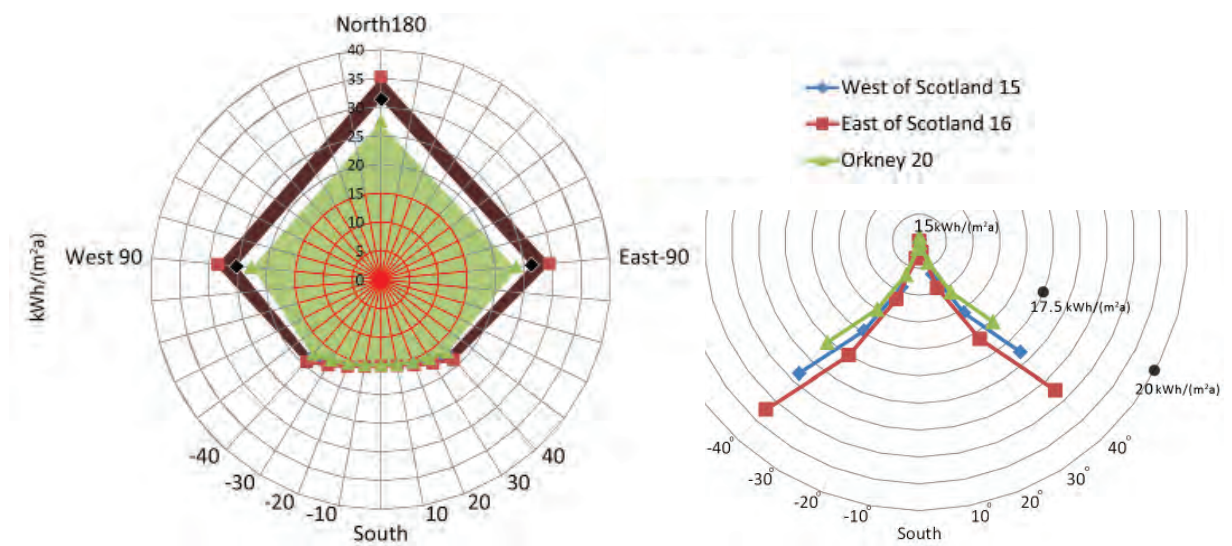


Figure 114- Fine Grain Orientation (Weighted U-Values)

between south and $\pm 40^\circ$ in orientation demonstrate a smaller variation between climates in comparison to Study 2B due to the weighted u-values. There is still around a $1.7 \text{ kWh}/(\text{m}^2\text{a})$ difference between the East of Scotland and Orkney at 40° from south towards the south west. In climates with lower solar isolation figures such as Orkney are less sensitive to variations in orientation due to their reduced reliance on solar gains therefore will allow for more flexible site positioning and potentially more varied urban layouts in these areas.

6.5.3. Study 2C: Roof Type and Roof Angle Study

This study determines the effect of the roof design on the SSHD of the prototype in the West of Scotland and Orkney, the extremes of the Scottish climate. The study answers the question:

- To what extent does roof form effect the SSHD using ULEH specification in Scotland?

PHPP uses the exposed external surface area to determine heat losses through the external envelope and roof form has a significant effect on the surface to volume ratio and also affects the area of roof exposed to the sun. This defines the area and effectiveness of roof mounted low carbon technologies which can be placed on the roof such as solar thermal panels (producing Domestic Hot Water) and solar PV cells (producing electrical energy) (S. A. H. Scottish Government 2011c). The roof pitch determines the efficiencies of roof-mounted solar thermal panels and solar PV panels. The efficiency of the collectors are determined by their angle and orientation and optimum figures can be calculated using the location latitude to calculate sun angles (Kern & Harris 1975; Fuller et al. 1982). The technology requires a roof to be between the angles of around 30° and 45° to work efficiently (Kern & Harris 1975)

The roof design can be important in establishing an 'identity' for the architecture and is influential in establishing strong formal relationships with historic built form (S. A. H. Scottish Government 2005b). The consumer market favours dwellings to resemble the archetypal house form with a double pitched or hipped roof (Richards 1994). The Scottish regional climate has traditionally effected the design and detailing of

buildings in Scotland, the majority have double pitch roofs for practical reasons such as keeping out rain and reducing snow loading.(S. A. H. Scottish Government 2005b). Roof form has a significant effect on the surface to volume ratio which in turn will affect the SSHD. Consequently, the design of the roof should be a balance between exposed roof area for solar panels, heat loss and qualitative formal design approaches. Three generic roof designs: flat, mono-pitch and double-pitch were compared to assess the effects of changing the surface to volume ratio, and varying the angle of incline from 0° to 50°, in 10° increments. These studies uses the housing prototype constants, with the exception of the wall areas, roof area and overall volume which are all variable due to the roof form.

Study Variables

Alternative Roof Designs

A series of designs were developed in Sketchup to ensure the accurate measurements of roof angles. [Figure 115]

- Flat Roof
- Mono Pitch Roof
- Double Pitch Roof

Alternative Roof Angles

- 0° to 50° in 10° increments

Climate Data

- Orkney
- West of Scotland

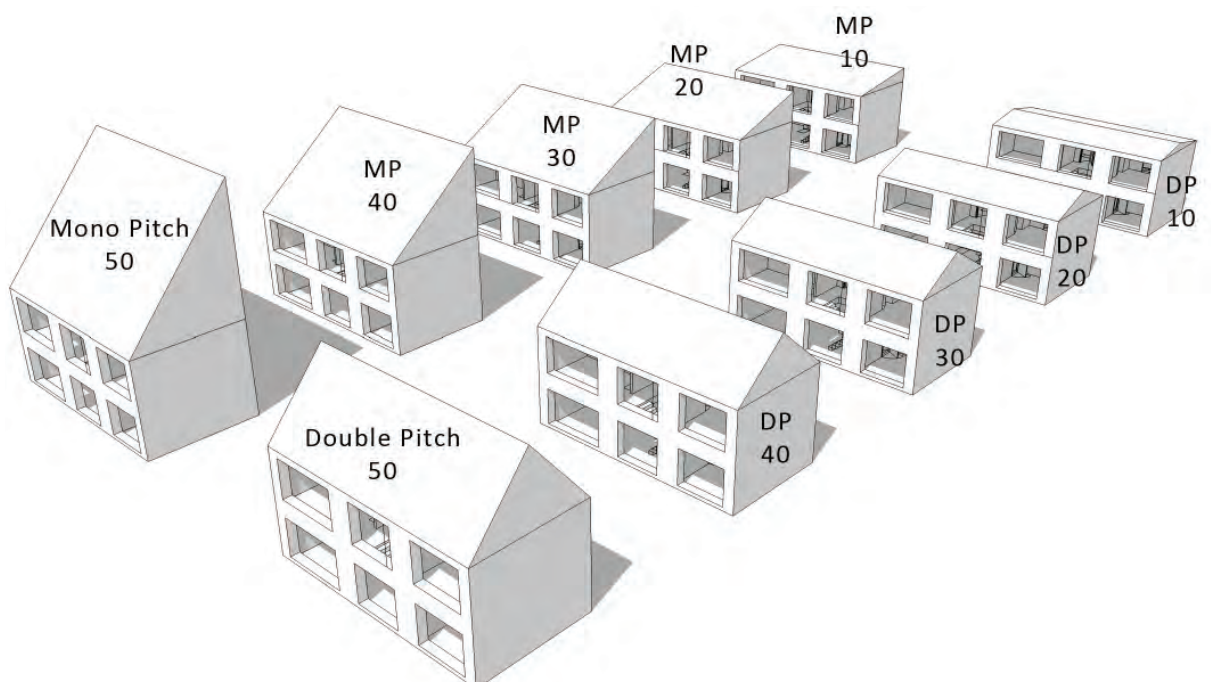


Figure 115- Roof Design Variations

Results and Analysis

[Figure 116]

The flat roof gave the lowest SSHD in the West of Scotland (8.5 kWh/m²a) with the lowest exposed roof surface area of 88.8m². However, the use of flat roofs in Scotland has historically not seen widespread residential use due to wet weather and the possibly of relatively large amounts of snow fall, particularly in elevated, rural areas. The use of the traditional 40° double pitch roof is suitable for the installation of renewable panel technologies and only increases the SSHD by 2.4 kWh/(m²a) with an exposed roof surface area of 105.5m². This roof design is more efficient and has less surface area which is useable for renewable panel technologies than the mono pitch of the same angle. However, the mono pitch results in a 4.7 kWh/(m²a) increase in SSHD and 58.4m² increase in roof surface area compared to the 40° double pitch roof. The results of the study illustrate that the pitched roof with associated qualitative features such as building identity and quantitative features such as loft space, solar collector area are still a viable option compared with flat and mono pitch roofs. Mono pitch roofs tend to be less viable due to increased heating losses when attempting to achieve the 30°-45° tilt most suitable for solar collectors due to the consequent increase in north facing wall areas.

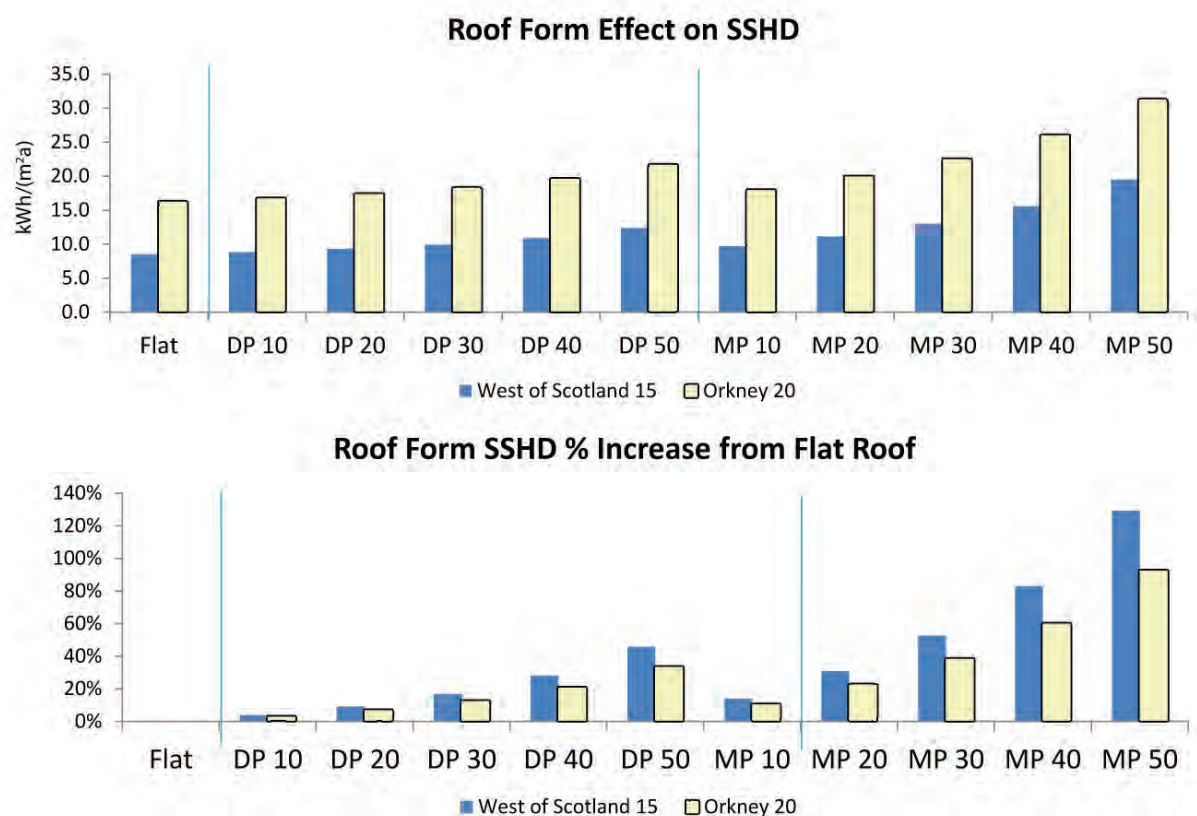


Figure 116- Roof Form Results

6.5.4. Study 2D: Dwelling Typology Study

The SSHD of different dwelling typologies are compared in the two extreme climate regions; West of Scotland and Orkney. Current market trends and economics have resulted in the majority of housing developments being composed of high numbers of detached housing types and in rural areas this statistic is further exacerbated (Scottish Executive 2013c, p.117). Rural areas are also comprised of a higher number of detached houses than urban areas (Scottish Executive 2012g, p.32]). Whilst detached housing is known to be the worst performing housing typology there is little quantifiable data available to define the effects on building energy performance. The dwelling typology effects the area of exposed surface of a dwelling and therefore has an effect on the heat losses. The study answers the following question defined in the methodology:

- To what extent does the use of an aggregated building typology reduce SSHD?

A variation of the prototype is used for this study. In this study the end elevations are defined as party walls which PHPP presumes to have no heat losses. This involves a simple alteration using the PHPP master file which alters the party walls properties in the Areas sheet to take into consideration the sheltering effect of the other joined property or properties.

Study Variables

- Detached Housing
- Semi Detached/End of Terrace Housing
- Terraced Housing

Climate Data

- West of Scotland
- Orkney

Results and Analysis

[Figure 117]

The results show that significant reductions in SSHD are possible due to the reduction in exposed surface areas in the semi-detached and terraced typologies. The West of Scotland showed the greatest decrease of 58% between the detached house type (11 kWh/(m²a)) and the terrace (7 kWh/(m²a)), while Orkney only resulted in a 40% reduction. This 40% reduction in Orkney would be sufficient to achieve the PH SSHD criteria at 13.7 kWh/(m²a). The semidetached typologies also demonstrate a reduction in SSHD relative to the area of the sheltered gable. It indicates that attached or aggregated housing forms are more effective and potentially more cost efficient in the both of the regions. The West of Scotland region would receive higher reductions in SSHD than Orkney without resorting to more expensive fabric specification increases. The housing typology used for future developments will have an effect on the building specification required to achieve ZHC and NZEB targets. If the proportion of new build housing typologies tended towards more efficient types such as semi-detached, terraced or aggregated types, this will have a major impact on future development morphologies.

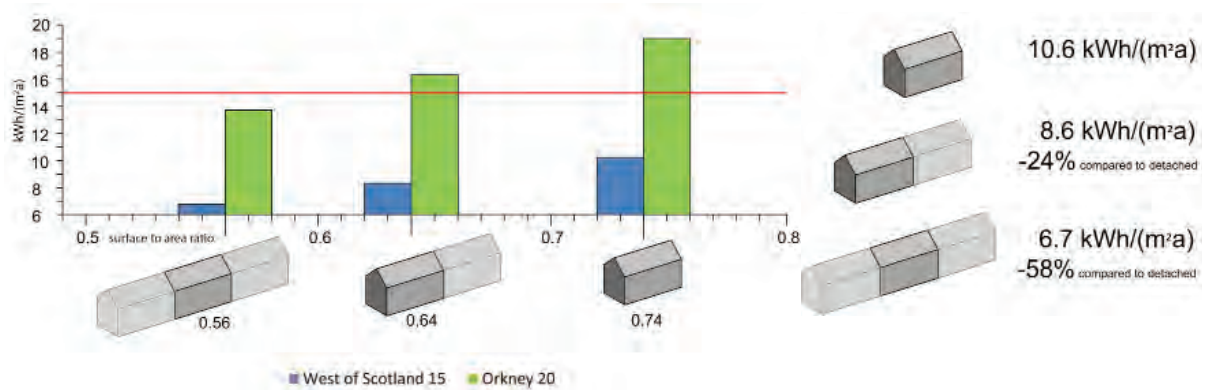


Figure 117- Dwelling Typology Results

6.5.5. Study 2E: North & South Facade Fenestration Study

The SSHD of varying the north and south glazing percentages is compared in the two extreme climate regions; West of Scotland and Orkney to answer the following questions:

- Does the inclusion of north facing glazing significantly affect the SSHD in Scotland?
- Does best practice guidance for south facing guidance apply to the extremes of Scottish regional climates?

In most cases PH houses use passive solar principles to maximise heat gains through south facing glazing and conserve heat by minimising glazing in north facing facades. However, eliminating north facing glazing in a house can be difficult and even undesirable particularly where strong contextual relationships between internal spaces and external environments are desirable (such as capturing northern views or naturally lighting a space from two directions). Furthermore the removal of north facing glazing may be impossible due to site constraints. Ultra-Low energy housing guidance suggests that large areas of south facing glazing should be around 50-55% of the surface area while north glazing should be minimised or eliminated.

Following these guidelines without a knowledge of the implications on SSHD may prevent house designs from taking full advantages of views and light available from northerly directions and creates plans reliant on natural light primarily from the south, east and west. The study uses the 107m² prototype as the base test model which has 3.8m² (6% of north facade) and 29m² (50% of south facade) glazed. The study varies the percentage of glazed area on both the north and south elevations from 10% to 90% in 10 degree increments. Similar studies have been performed by W Feist, J Schnieders, and BERE Architects in different climate data areas across Europe (Passivhaus Institut & Feist 2006; Schnieders 2006; BERE Architects 2010b). The majority of these studies explore only south facing glazing.

Study Variables

The house type has 6 simple fixed pane window to the south. The north facing glazing study replicates the south facing glazing approach on the north side. The window sizes are kept equal therefore retain window frame heat losses. The only variable inputs that PHPP require for each of the studies are the sizes of the six

windows and their orientations. The particular arrangement of the windows does not require entry into PHPP.

Climate Data

- West of Scotland
- Orkney
- (East of Scotland)

North Fenestration Study Variables

- South Fixed at 29m² (50%)

North Glazing

- Overall glazing percentage of the north façade varies from 10% (6m²) to 90% (55m²) (10 degree increments)

Results and Analysis

[Figure 118]

The results show that larger south facing windows reduce SSHD in both regions, and have the greatest effect in regions with greater solar insolation levels. However, while the study shows there to be an increase in useful solar gain in the winter, the overall solar gain utilisation falls due to an excess of solar gain in the summer and a greater risk of overheating and increased temperature swings. Increasing south facing glazing from 50% to 90% of the façade in the West of Scotland reduces the SSHD by 3.3 kWh/(m²a) whereas reducing the area to 10% increases the SSHD by 17.1 kWh/(m²a) from the original 10.6 kWh/(m²a). Values lower than 30% south glazing lead to a more significant increase in SSHD in the West of Scotland. The differences in Orkney were not as extreme as this climate is less solar gain reliant. The use of larger south facing glazing in climates with high solar insolation such as the East of Scotland will have a more beneficial effect in the winter however they are likely to have a low SUF therefore have more chance of overheating due to an excess of solar gain in the summer. Based on these results a separate study in the East of Scotland region showed a more marked increase in the SSHD with a reduction in south glazing area. This indicates that the higher Gt Value compared to the West of Scotland makes the solar insolation available a more important factor in the design of passive solar principles housing in East of Scotland. This also shows that the West of Scotland has a more amenable climate with a better balance between temperature and solar insolation.

South Fenestration Study Variables

- North Fixed at 3.8m² (6%)

South Glazing

- Overall glazing percentage of the south façade varies from 10% (6m²) to 90% (55m²) (10 degree increments)

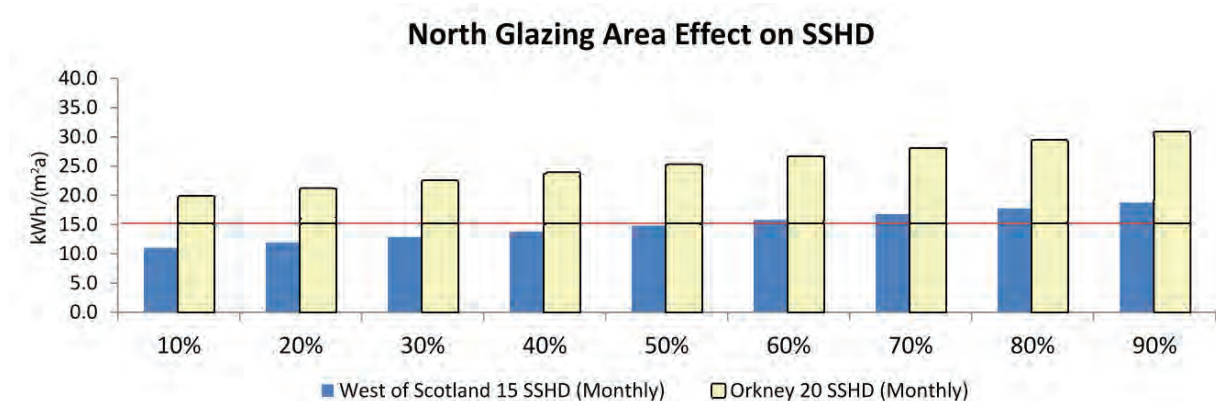


Figure 118- North Glazing Effect on SSHD

Results and Analysis

[Figure 119]

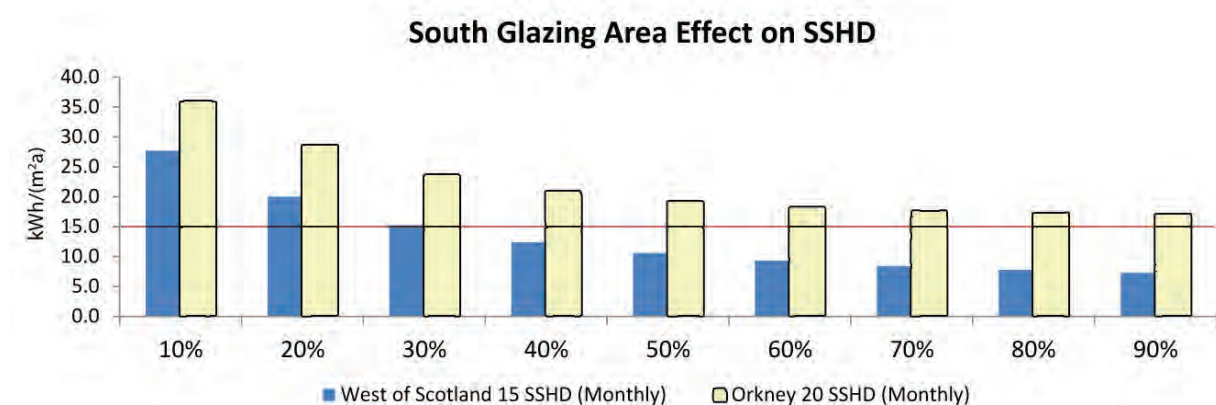


Figure 119- South Glazing Effect on SSHD

Increasing the area of north facing glazing results in a linear increase in SSHD and heat load in both climates. This translates into a $\sim 10 \text{ kWh}/(\text{m}^2\text{a})$ raise in SSHD in both climates when increasing glazing from 10%-90%. This is due to the increased heat losses through the glazing with no increase in solar gain contribution. It was shown that in the West of Scotland, the benchmark criteria could be met with an increase in north glazing up to 50% from the original prototype value of $10.6 \text{ kWh}/(\text{m}^2\text{a})$ (6% glass) to $14.8 \text{ kWh}/(\text{m}^2\text{a})$. The climates that show a higher SUF when analysed with the prototype can utilise more of the solar insolation available to enable the reduction of heating demand without adding to overheating.

Fenestration Study Summary

Preliminary figures are consistent with broad conventions and similar to BERE study however show different range of variation in SSHD. The results show a smaller variation of Specific Heat demand to that of the BERE study (BERE Architects 2010a). These variations are due to the variance in climate and building design. The results do not suggest a clear optimum area of glazing for different regions across Scotland. The best practice 50% glazing to the south façade is applicable in both areas however SSHD can be reduced further with larger areas of glazing at the risk of overheating. The optimal area is very much dependant on the particular climate and design in question. However, results suggest that the impact of alterations from the norm are not as critical as best practice state, particularly with regard to north facing glazing.

6.6.Study 3- Effects of Ventilation Losses and Fabric Specification on SSHD

[Figure 120]

The two technical studies utilise the weighted u-values defined in Study 1B to achieve 15 kWh/(m2a) in each of the climates. The technical studies illustrate the variations between Passivhaus and ULEH technical systems and specification in comparison to current building regulations (airtightness) and proposed ZCH standards. The first part of the study quantifies the effect of airtightness values and the effect of MVHR on the SSHD. The building fabric performance study analyses the variation between ZCH/FEES, ZCH/Advanced Specification and PH fabric performance specification and their effect in SSHD.

6.6.1. Study 3A: Effects of Airtightness and use of MVHR

Variations in SSHD caused by the use of MVHR and changes to airtightness specification levels are compared in this study. It firstly investigates the influence of PH specification airtightness rates with and without MVHR, then goes onto compare this with ZCH and ZCH and Scottish Regulations air change rates without MVHR.

The study answers the following questions:

- Do high levels of airtightness have a significant effect on SSHD in Scotland?
- How much does the use of an MVHR unit contribute to SSHD reduction in ULEH across Scotland?

Chapter 6- Study Structure









			Section
	Climatic Region	1A 1B	6.4
	Orientation	2A 2B	6.5
	Roof Form	2C	
	Typology	2D	
	South Glazing	} 2E	
	North Glazing		
	Airtightness & MVHR	3A	6.6
	ZCH Specification	3B	

Figure 120- 3X Study Structure

The data for the building regulations airtightness study is from the Scottish *Technical Handbook 2013 – Domestic* defines the Scottish minimum regulations for air infiltration as $10\text{m}^3/(\text{h.m}^2)$ (Scottish Executive 2013h, p.377). However, currently there is no Scottish ZCH airtightness specification so the UK Zero Carbon Hub ZCH FEES specification is determined as $5.2\text{m}^3/(\text{h.m}^2)$ provided in the *Cost Analysis: Meeting The Zero Carbon Standard* document (Zero Carbon Hub 2014c, p.25). Both UK ZCH and Scottish regulations define airtightness in air volume over square meters per hour ($\text{m}^3/(\text{h.m}^2)$) whereas Passivhaus defines air changes per hour at 50 Pascals (ac/h@50pa). The UK units require conversions into the Passivhaus units to be entered into the PHPP. This study does not take into account the best practice suggestion for fitting MVHR in buildings with high airtightness levels and takes basic guidance from the ZCH documentation.

Study Variables

MVHR & Airtightness

- PH Certified MVHR Unit – Passivhaus airtightness 0.6 ac/h@50pa
 - No MVHR – Passivhaus airtightness 0.6 ac/h@50pa
- No MVHR- Scottish Building Standards $10\text{m}^3/(\text{h.m}^2)$ (2.1 ac/h@50pa)
- No MVHR- ZCH FEES $0.2\text{m}^3/(\text{h.m}^2)$ (1.1 ac/h@50pa)

Climate Data

- Orkney
- West of Scotland

U-Values

Weighted for $15\text{ kWh}/(\text{m}^2\text{a})$ in Climate:

- Orkney: $0.091\text{ W}/(\text{m}^2\text{K})$
- West of Scotland: $0.157\text{ W}/(\text{m}^2\text{K})$

PHPP data input variables:

Airtightness Level

- ZCH FEES standard: $5.2\text{m}^3/(\text{h.m}^2)$ is calculated to be 2.1 ac/h@50pa for the 107m^2 prototype.
- Scottish Building Standards: $10\text{m}^3/(\text{h.m}^2)$ is calculated to be 1.1 ac/h@50pa for the 107m^2 prototype.

MVHR

- On\Off

Results and Analysis

[Figure 121]

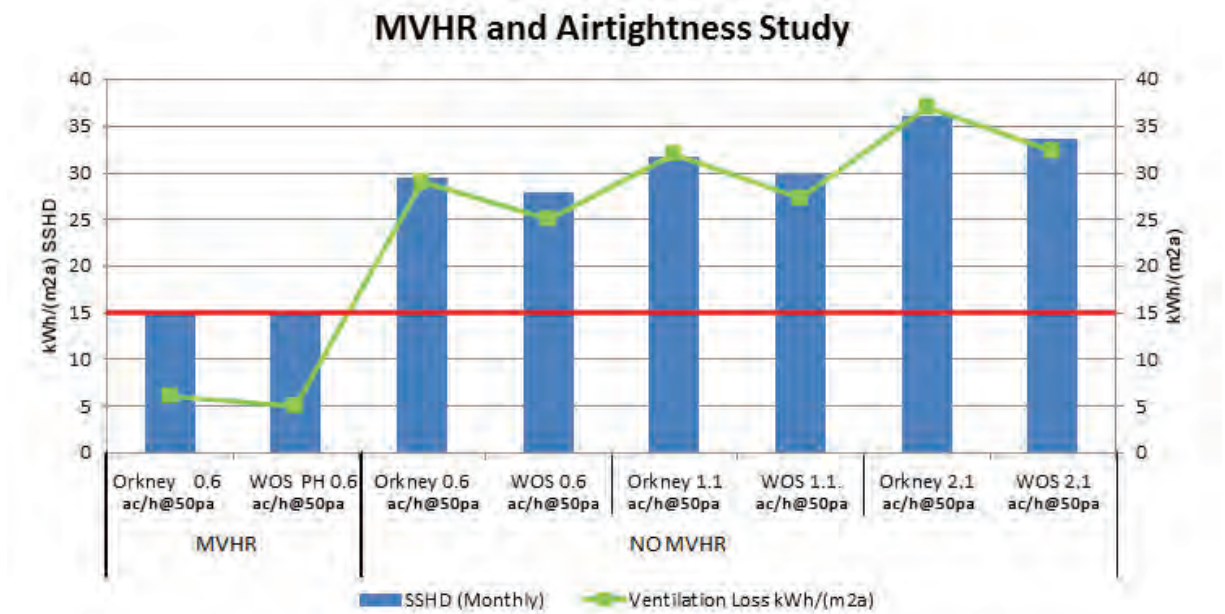


Figure 121- MVHR and Airtightness Results

The results demonstrate the significance of the MVHR in the Passivhaus concept particularly in colder climates. The omission of the MVHR in Orkney doubles the SSHD from 14.9 kWh/(m²a) to 29.56 kWh/(m²a), the West of Scotland demonstrates a similar figure. The increase is due to the increase losses through natural ventilation in the heating season. The rise in SSHD between the PH without the MVHR and the ZCH FEES airtightness is ~2.2 kWh/(m²a) in Orkney and ~1.9 kWh/(m²a) in the West of Scotland. This increase is significant when the variation in airtightness can be achieved through better quality on site controls. Additionally the ventilation losses will stay consistent through the life of the building therefore over time the increased heating costs are additive with a constant heat loss figure. The variation from PH airtightness without MVHR to current regulations results in an increase of 6.6 kWh/(m²a) in Orkney and 5.66 kWh/(m²a) in the West of Scotland. The strict Passivhaus airtightness target has been proven to be achievable in Scotland and the rest of the UK therefore when attempting to achieve ULEH implementing this target is sensible. This study does not take into account exposed sites with high wind speeds such as those found across rural Scotland however it can be presumed that lower airtightness values would result in higher heat losses. This study demonstrates the significant impact that using an MVHR can have on SSHD particularly in cold, Scottish climates. However experience using SAP through practice has demonstrated that it does not consider the ventilation heat loss savings through the use of a MVHR and only considers the electricity usage for the running of the machine which increases the overall carbon emissions of the building. This creates conflicting performance results between the Passivhaus concept and ZCH.

6.6.2. Study 3B: ZCH, Building Regulation and Passivhaus Fabric Specification Study

The study compares the 107m² prototype dwelling designed to PH specification and two ZCH fabric specifications and answers the following question:

- What are the impacts of regional climate and the ZCH FEES specification on SSHD in Scotland?

Current UK ZCH definition has different options to achieve the future target. The “*Cost Analysis: Meeting The Zero Carbon Standard*” document provides the most up to date ZCH specifications and different approaches to achieve ZCH (Zero Carbon Hub 2014c, p.25). The two main specification routes are defined in this document

- Minimum FEES specification
- ZCH Advanced (close to Passivhaus)

The weighted u-values for Passivhaus are used for each climate to illustrate the regional effect that the specification will have on SSHD from the 15 kWh/(m²) benchmark. The use of the extremes in Scottish climate will demonstrate the variation between regional climate data and the average climate data used in the SAP calculation method for each fabric efficiency standard.

Study Variables

Specification Variations

- ZCH FEES Specification (No MVHR)
- ZCH Advanced Specification (MVHR)
- Passivhaus Specification (MVHR)

Climate Data

- Orkney
- West of Scotland
- UK Average

U-Values

Weighted for 15 kWh/(m²a) in Climate:

- Orkney: 0.091 W/(m²K)
- West of Scotland: 0.157 W/(m²K)
- UK Average: 0.132 W/(m²K)

Specific Specification input variables:

[Figure 122]

Fabric Study

Detached House

	FEES	Advanced Practice ZCH PH	Passivhaus Orkney Fabric	Passivhaus WOS Fabric
Walls	0.15	0.15	0.09	0.16
Floor	0.13	0.15	0.15	0.15
Roof	0.13	0.11	0.09	0.16
Windows	1.2	0.8	0.77	0.77
Doors	1	1	0.81	0.81
AT	5.2	1*	N/A	N/A
PH AT	1.1	(0.2) 0.6	0.6	0.6
MVHR	No	Yes	Yes	Yes

Figure 122- Fabric Study Inputs

Results and Analysis

[Figure 123]

The ZCH Advanced specification out performs the Passivhaus criteria with an SSHD of 12.1 kWh/(m²) using the average climate data and complies with an SSHD of 15.45 kWh/(m²) in the West of Scotland. This study utilises a best practice prototype with optimal orientation with no overshadowing. The results confirm that the ZCH Advanced specification will work in the least harsh Scottish climate, using a well-designed compact volume taking full advantage of solar gains. In the West of Scotland any deviation from this ideal would

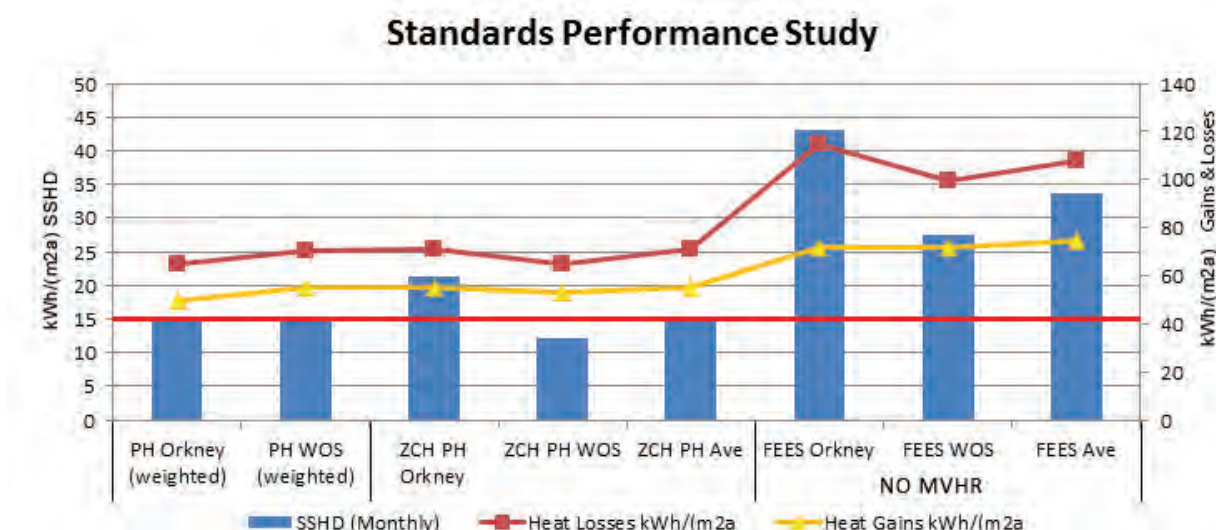


Figure 123- Fabric Study Results

increase SSHD beyond the ULEH Passivhaus target in the West of Scotland. Due to the increase climatic demands in Orkney results in a 6.1kwh/m² increase in SSHD over the PH accreditation benchmark despite the best practice building design. The FEES standards see significant increases from Passivhaus SSHD with Orkney increasing by almost 28 kWh/(m²) and 12.4 kWh/(m²) in the West of Scotland. Interestingly the FEES specification has the ability to achieve Passivhaus standard in the West of Scotland with the addition of an MVHR. Currently the main difference between the Passivhaus and ZCH Specifications are the dynamic and

static natures of the methodologies. The ZCH Advanced and FEES specifications currently rely on average climate data and backstop values. This means that any significant deviation from best practice is likely to have a major effect on SSHD. The likelihood is that the majority of developer and architect designed houses will not have ideal orientations and compact forms. This implies that even the ZHC Advance practice is likely to lead to higher than Passivhaus SSHD in many cases with the current methodologies.

6.7. Research Study Conclusions

The regional weather data study (1A) demonstrates that climatic variation across Scottish regions due to complex geographical and metrological factors can lead to significant increases in SSHD with the worst case being an increase of up to 80%. Study 1B illustrates a 45% SSHD performance gap between the worst performing regions in Scotland (Orkney) and the UK average climate. The UK's legislative domestic energy rating methodology SAP uses the equivalent BRE UK average data for all areas in the UK therefore it is likely to produce a similar 45% shortfall in predicted heating requirement in the same area of Scotland. Study 1B also demonstrates the significant effect that climatic variation has on construction build up thickness and specification to achieve ULEH criteria. The wall and roof thickness using typical timber frame construction would have to increase by 149mm to compensate for the increased heating demand across different areas across Scotland and this will have a consequent effect on building construction costs.

The orientation studies (2A & 2B) demonstrates that the alteration of orientation from south has significant effect on SSHD, particularly in climates that have more reliance on solar gains such as the East of Scotland with the results showing an increase of 164% with a 180° deviation from south. Despite the majority of guidance stating a relatively large permissible variation from south ($\pm 45^\circ$ or $\pm 30^\circ$) this research has shown that there is an increase in SSHD caused by relatively small orientation changes in certain areas of Scotland when designing ULEH. This effect is not highlighted or discussed in current best practice guidance and only mentioned in passing in ULEH UK guidance. However, the research also shows there to be greater scope in varying orientation whilst still complying with PH criteria than previously thought using small increases in thermal specification, particularly in areas with low solar heat gain reliance.

The other study findings (2C, 2D, 2E) demonstrate that altering building form can have a significant effect on the SSHD across regions.

Study 2C demonstrates the viability of traditional roofing forms. The double pitch 40° form only increases the SSHD by around 2.4 kWh/(m²a) when compared with a more thermally efficient flat roof. The double pitch design is more SSHD efficient but with less solar collector area than the mono pitch. However, the mono pitch roof significantly increases SSHD in comparison to the double pitch roofs of the same angle due to the increased surface area of north wall.

Study 2D establishes that aggregated housing typologies illustrate worthwhile reductions in SSHD, which should encourage wider use of terraced and to a lesser extent semi-detached housing typologies in all climatic regions. The detached house was found to have 58% higher SSHD than the equivalent terrace in the West of Scotland region. The semi-detached housing typologies illustrate up to a 28% reduction in SSHD in comparison to the detached house. These reductions will be heavily dependent on the housing design and area of gable as the SSHD increase is proportional to the increase in exposed surface area. The results should be relatively conservative due to the larger north and south facades relative to the east and west gables.

The results of the glazing study (2E) demonstrate the importance of balanced glazing design in ULEH to achieve low SSHD which correlates with previous research in this area. Large areas of south facing glazing will generally lower SSHD demands with a positive window heat balance, but with the increased chance of overheating and increased glazing costs. The reduced area of south facing glazing in the prototype was

shown to increase the SSHD by as much as 17.1 kWh/(m²a) in the West of Scotland due to a vast reduction in solar heat gains.

The impact on north facing glazing (2E) however was proven to have a more generous design envelope than best practice suggests. Although north facing glazing does not have a beneficial effect on SSHD the high performance glazing reduces losses to allow for greater planning variations. The climates which are less reliant on solar gains illustrate a greater flexibility in facade design with a smaller detrimental effect on SSHD. This suggests the possibility of a greater variety of climatically responsive solutions.

The importance of MVHR has been proven by the research study (3A), particularly in cold climates where the SSHD can double with the omission of the unit. Airtightness in construction was shown to have a smaller but not insignificant impact on SSHD. The use of a Passivhaus fabric specification can result in a 20% increase in SSHD between the Passivhaus target and current regulations. Both the high airtightness level and MVHR are not mandatory for the current definition of ZCH.

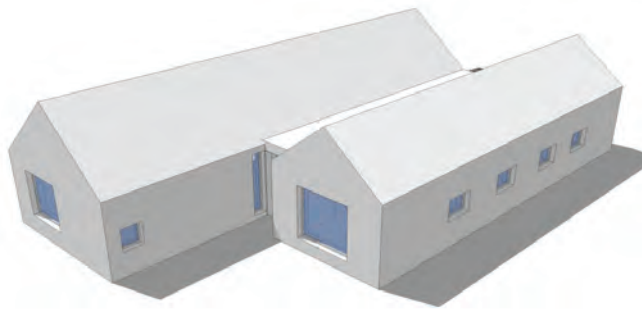
The fabric specification (3B) study confirms the increase of around 45% in SSHD between the UK average and Orkney climate data using the ZCH FEES specification. This implies that the SAP estimation of a ZCH SSHD in Orkney could be around 45% less than is actually possible in that climate. This use of static minimum fabric performance specifications regulated by the average climate data in SAP will increase actual energy requirements in some areas and reduce them in others such as the West of Scotland which performs better than the average UK climate and therefore SAP estimates.

Study 1B and 3B both demonstrate the UK's legislative approach of utilising UK average climate data to determine how a particular house will perform is likely to produce unrealistic estimates in some regions given the complexity and extent of the Scottish climatic variation. This is of particular importance as current legislation assessment methodologies do not encourage the need for climatically responsive housing as the wide climatic differences across Scotland are not recognised in the calculation tool SAP.

The research finding from studies 2A, 2B and 2D have shown the extent to which both orientation and typology can influence SSHD without necessarily resorting to high-technology responses. Study 2C demonstrates the viability of traditional 40° double pitch roofing forms with relatively low SSHD increases from flat roofs coupled with the ability to efficiently fit solar panels. Study 3D reinforces the impact of MVHR and the contribution that high levels of airtightness are likely to make in reducing SSHD in all areas of Scotland. The average UK climate (1B) and fabric specification (3B) studies reinforce the requirement for regional specifications to reliably achieve ULEH and ZCH in all areas of rural Scotland.

ANALYSIS AND OPTIMISATION OF QUALITATIVE SCOTTISH EXEMPLARY DESIGN

Chapter 7



Borerraig House Study Model

7. PASSIVE SOLAR ANALYSIS AND OPTIMISATION OF QUALITATIVE SCOTTISH EXEMPLARY DESIGNS

This study determines the extent to which a number of Scottish Government endorsed housing examples need to be modified for lower SSHD in the extremes of Scottish climate and what effect these changes have to the formal design. These examples have either been endorsed in the Scottish Governments database of '*Inspirational Designs*' or from initiatives endorsed by the Scottish Government and demonstrate strong contextual relationships to place and landscape exemplifying high quality approaches to design in rural areas (Scotframe & Scottish Government 2009; Comhairlie nan Eilean Siar 2010; S. A. H. Scottish Government 2012d). The examples have been designed by well-known architectural practices and Scottish timber construction firms (rather than mass market housing developers), and appear to largely rely on intuitive responses to environmental issues as opposed to in-depth quantitative studies. The specification of each of the built examples is closer to the 2010 Scottish Technical Building Standards minimum standards rather than ULEH or ZCH (St. Andrew's House Scottish Government 2009c). Three non-exemplar control designs are analysed. These are the three typological variations of the 107m² best practice Passivhaus (ULEH) Doll's house developed for Chapter 6 and in section 6.5.4, study 2D; detached, semi-detached and mid terrace. These designs are used as a control benchmark to determine u-values and best practice performance for the three typological variations in the study. The designs are modelled in PHPP using a standard PH fabric specification tailored to each region and typology in order to determine the comparative design efficiency of the different examples. A similar customised PHPP methodology to Chapter 6 is used to analyse seven Scottish Government exemplars of high quality rural housing. The study quantifies the energy efficiency of the building forms in terms of SSHD and certain sections of the study also quantify the heat load (HL) performance of the designs. The heat load determines the size of the heating system required to achieve 20°C throughout the year. Results of this study quantify for the first time whether the design in its original form can meet ULEH standard and if not what changes need to be implemented to achieve this. In order to do so factors including orientations, window positioning, and sizing are modified and the changes assessed in terms of their impact on the formal design.

The principle objectives are to:

- establish the energy efficiency of existing exemplary qualitative designs and attempt to optimise their building forms for ultra-low energy performance.
- balance qualitative design considerations with quantitative energy use issues to define the optimal building form for the extremes of Scottish climate.

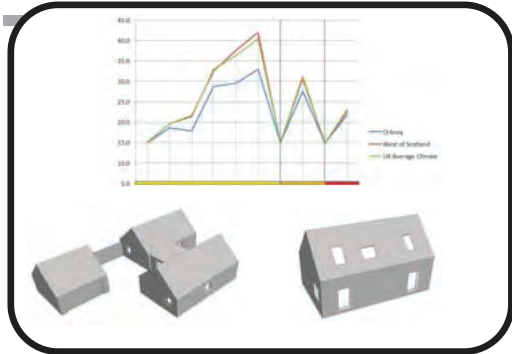
The study includes the following variables:

- exemplar designs (7 models and 3 control models)
- optimising orientation from due south;
- optimising percentage and positioning of north, south, east and west facing glazing.

[Figure 124] Illustrates the outline of the studies within the chapter.

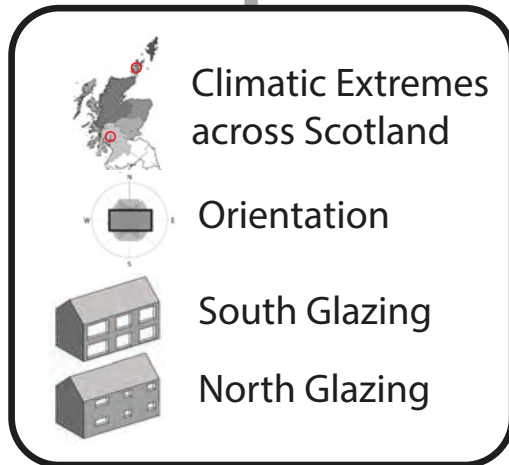
Chapter 7- Study Structure

Quantitative Comparative Analysis



Section
7.3

Optimisation of 7x Exemplars through PHPP



Section
7.4

Figure 124- Studies Structure

7.1. Scottish Exemplar House Designs

Seven key exemplary rural housing projects are discussed in detail in terms of their philosophy, design, spatial organisation, and response to context. Each design is cited either on *the Scottish Governments Inspirational Designs* web pages, endorsed by Scottish Government Initiatives, winners of the Satire Housing Awards or discussed by Architecture and Design Scotland (S. A. H. Scottish Government 2012d; Saltire Society 2011; Architecture and Design Scotland (A+DS) 2014a). A brief overview of the practice and explanation of each of the designs is outlined in the following section.

Inspirational Designs

The Scottish Government's Inspirational Designs is an online database that showcases the best quality housing design and placemaking in Scotland (S. A. H. Scottish Government 2012d). The designs have been selected through winners or commendations in the national and local design awards from the last three years (*ibid*). The database can be navigated in various ways; alphabetically, through region or through project type, making it simple to identify award winning rural housing projects. Examples from The Scottish Sustainable Communities Initiative (SSCI) and Scotland's Housing Expo are also included in the Inspirational Designs database. This was a key resource in order to select designs for the *Analysis And Optimisation Of Scottish Exemplary Designs* study.

Scottish Government Initiatives

There are various Scottish Government Initiatives that aim to showcase their design aspirations or demonstrate alternative methods for producing high quality design responses. The Polnoon re-development and the Scottish Housing Expo are both examples of large scale Scottish Government design Initiatives discussed in section 3.3.3. The Government also run smaller initiatives specific to smaller regions which may involve presentations from key architects and design studies or production of design guides. Two examples of these are *Orkney Masterplan Training* and *Rural design: Future Landscapes*, discussed in section 3.2.3 (Scottish Government 2009b; St. Andrew's House Scottish Government 2011b).

Satire Society Housing Awards

As described in section 3.2.6 the Saltire Society have run housing awards since 1937. Key examples of Scottish residential architecture have received awards from the Satire Society. Many of the designs found on the Inspirational Designs have been selected due to the fact they are Saltire Housing Award winners or runners up.

Architecture and Design Scotland (A+DS)

A+DS are Scotland's champion for excellence in placemaking, architecture and planning and work closely with the Scottish Government's Architecture and Place division. Their literature contains references to key architects and projects such as the *National Architecture* position paper on the evidence of a renewed interest in Critical Regionalism in Scotland that highlights Dualchas and Rural Design (Architecture and Design

Scotland (A+DS) & Guest 2011). See section 3.2.5 for more details on A+DS.

Selection Process

The Inspirational Designs website is divided into urban and rural projects of varying scales, there a number of single house new build projects. However, many projects were deemed unsuitable for use in the study as they are not applicable for use as models for mass-market or affordable housing development e.g. they are too individual, site specific, small, large or highly complex and therefore considered unaffordable. Complex designs include *Craignish* by Cameron Webster Architects and *House At Loch Awe* by McInnes Gardner Architects [Figure 125]. Some examples on the webpage are either too small, such as the modern holiday homes such as the *Fiscavaig House* and *Black House* by Rural Design, or too large, traditionally styled designs such as the *Ardmhor Lodge* by SBA Architects Ltd (S. A. H. Scottish Government 2012c; S. A. H. Scottish Government 2012a; S. A. H. Scottish Government 2013c) [Figure 126][Figure 127]. Examples from the Scottish Housing Expo such as Rural Design's *Secret Garden*, Graham Massie's *White House* and Studio Kap's *Hardcore Soft* were thought to be too individual for wider development. Other examples from the *Inspirational Designs* website such as Simon Winstanley Architects *Ford House*, ICOSIS Architects *Fir Chlis* and



Figure 125- McInnes Gardner Architects, House At Loch Awe (S. A. H. Scottish Government 2013c)



Figure 126- Rural Design, Fiscavaig, Isle of Skye (S. A. H. Scottish Government 2012b)



Figure 127- SBA Architects, Ardmhor Lodge, Isle of Lewis (S. A. H. Scottish Government 2012c)






Figure 128- ICOSIS Architects Fir Chlis, Harris

Tom Edwards 34A Eoligarra were considered however, detailed drawings of the projects were not obtainable from the architects (Scottish Executive 2012c; Scottish Executive 2012b; Scottish Executive 2012a)[Figure 128]. Examples of Gökyay Deveci's work such as the Model D House were also considered, but many of these are already designed to or near to Passivhaus, and it is not the intention of this study to attempt to improve buildings that already meet ULEH status. The range of examples were chosen because they are the most suitable for possible mass market development in different areas with designs that can be easily replicated and adapted to suit different contexts. The selection of designs also demonstrate a range of approaches with forms that attempt to recognise or are influenced by traditional or historic forms as these align with the recommendations in the various PAN guidance outlined in Chapter 3. This formal reference meets the PAN documentation guidance for fitting into existing settlements.

Exemplar Study House Details

[Figure 129]

Prototype:	Boreraig	R2 House	Clousta
Architect	Dualchas	Rural Design	Scotframe
Date	2012	1999	2009
Area	Skye	Highlands	NVA
Stories	1	1.5	1
Image			

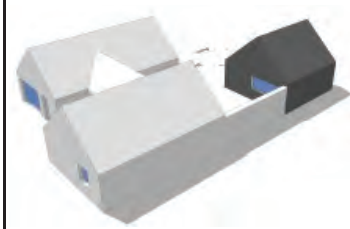

Prototype:	Outer Hebrides	NORD Terrace
Architect	Scotframe\ Proctor Matthews	NORD
Date	2011	2011
Area	Outer Hebrides	Inverness
Stories	1	2
Image		

Figure 129- Exemplar House Designs

7.1.1. Dualchas, Boreraig

Dualchas Architects, formally known as Dualchas Building Design is an award winning firm which was founded in 1996 by brothers Neil and Alasdair Stephen. Following Mary Arnold-Forster joining the practice in 1999, Dualchas are now widely considered as one of the leading contemporary rural Scottish architects, with Maudlin considering them as having the most considered approach to contemporary house design and Scottish Highland identity (Maudlin 2009b; Brown 2012). '*Dualchas*' comes from the Scottish Gaelic term for hereditary rights (Maudlin 2009b). They are based in the Isle of Skye in a small studio with a satellite Glasgow office. Dualchas is a small architectural design firm, however, they also have a division which develops more generalised kit houses called Hebridean Homes (Hebridean Homes 2014). They have an extensive portfolio mainly, but not limited to, residential new builds in Scotland, with experience in renovations, community centres and international commissions.

Design Approach



Figure 130- Dualchas, Dornie, Lochalsh (2005)

Dualchas describe themselves as having “a great deal of experience in design for sensitive rural sites” and they describe their work as “a modern vernacular for the Scottish countryside based on traditional architecture” (Arnold-Forster & Dualchas 2008). Dualchas’ ethos is summarised as: “by combining modern ideas and technology, with a respect for the past, we offer architect-designed solutions which complement our natural and built environments” (Dualchas 2013a). Dualchas offers an affordable adaptable alternative to the ‘scourge of the alien-kit house’ (Dualchas 2013b). Their houses are based on a reinterpretation of the traditional white and black houses using small compact footprints and simple geometric forms constructed using a limited material palette and careful reductive detailing which reflects the Calvinist appearance of the existing architecture [Figure 130]. They combine this with a contemporary approaches to spatial planning with large internal volumes and open plan spaces using expansive areas of glass to connect the interior environment with the open landscape. Top lighting and careful orientation of windows to connect spaces and views and maximise the different qualities of the northern light help to make the comparatively small

internal spaces feel substantially larger. Features that address the specific issues of living in a highland/island climate e.g. eroded loggias protected from the wind and large sliding screens to protect from the 'midge' and harsh wind driven rain. They often use only white render and timber cladding with metal detailing for the exterior surface treatment (Arnold-Forster & Dualchas 2008). The white render relates to the traditional mid-18th-19th century farmhouses and cottages. The timber cladding is often untreated and weathers to the colour of the surrounding rock and landscape (ibid). Many Dualchas' projects have the appearance of the classical traditional farmhouses and cottages, however, they are often constructed from timber frame. This is not only a stylistic feature, due to the harsh climates Dualchas often employs large section timber frame construction with high levels of insulation, large cavities and a block outer skin. This enables some detailing styling cues to be inherited from traditional buildings, with eaves and roof detailing with little or no overhang and deeply recessed windows [Figure 131]. Dualchas designs often feature large open plan living spaces, open to the apex of the roof, which shares similarities with the internal arrangement of the Blackhouse (Dualchas 2013b).



Figure 131- Dualchas, Ardivachar, South Uist (2005)



Figure 132- Dualchas, Cliff House, Galtrigill (Dualchas 2014)



Figure 133- Dualchas, Raasay Community Centre (2007)

Arnold-Forster explains that while Dualchas has developed a certain language, its recent work is different. This is perhaps a realisation of the challenge "when an architect strives to make a mark on the landscape" (Brown 2012). Some more recent Dualchas work moves away from the typical archetypal pitch roof cottage in the landscape and moves to flat roof, timber clad flat roofed forms such as the Tigh Port na Long house and

Cliff House, Galtrigill (Dualchas 2014) [Figure 132]. Interestingly the progression of Dualchas' work appears to reflect Scottish architectural history from the historic Blackhouse to the classical white cottage, to modernist mono pitched and flat roofed fully timber clad designs . Their larger scale designs such as the community centre on Rassay utilise larger agricultural forms which resemble industrial barns (Dualchas 1998; Dualchas 2006)[Figure 133].

Boreraig, Skye



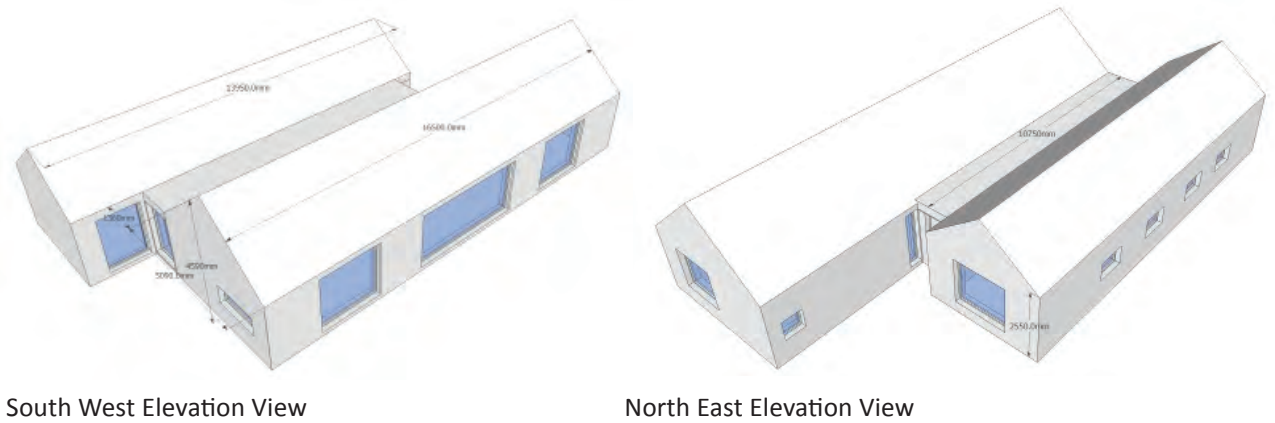
Figure 134- Dualchas, Boreraig House (Dualchas 2012)

[Figure 134]

The two bed house at Boreraig, Skye is a winner of the 2012 Saltire Society Single Dwelling award and is cited on the Scottish Government *Inspirational Designs* page (S. A. H. Scottish Government 2012d; Saltire Society 2014a). The house has also seen much international publicity across the internet on design blog websites. This house could be argued as being one of the “*most striking domestic projects*” and also their most successful with a myriad of awards from; IAA (Inverness Architectural Association), RIAS (Royal Incorporation of Architects in Scotland), Saltire Society and the Scottish Design Awards (IAA 2012; Brown 2012; Dualchas 2012; Saltire Society 2014a). Conceptually the house is unobtrusive in the landscape and the forms are likened to two larch-clad “sheds” sliding past each other (Brown 2012; Saltire Society 2014a). The two sheds take the archetypal shed or cottage form that are long and thin in plan, single storey with a double pitch roof (Dualchas 2012). This creation of three elements creates a simple parti, the main living spaces, the bedroom and entrance wing, and a studio (Saltire Society 2014a) [Figure 135]. This allowed the building to have narrow spans and low roofs (*ibid*). Internally the spaces make use of the pitched roof, a connection to the spatial characteristics of the traditional Blackhouse [Figure 136]. Another connection to the Blackhouse is the cooking area placed in the middle of the living space (Architecture and Design Scotland (A+DS) & Guest 2011). The house is surrounded by a dry stone wall which roots the new building into its context. It integrates vernacular inspired details such as timber storm shutters to relate to traditional buildings.

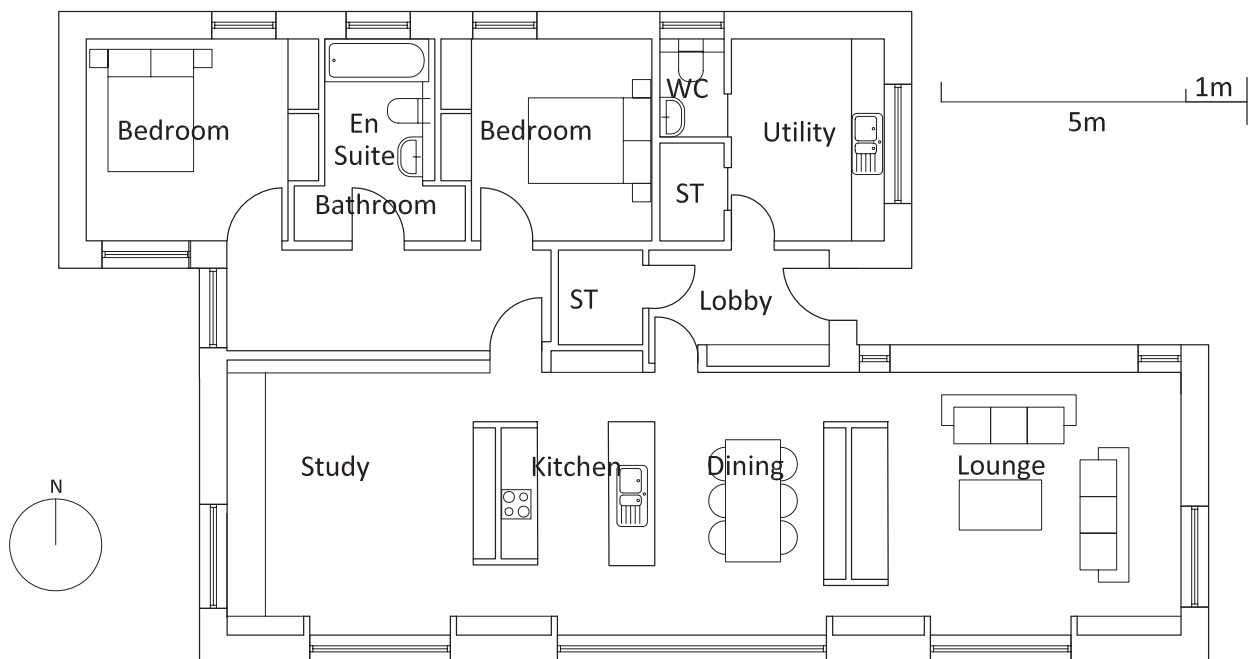


Figure 136- Dualchas, Borerraig House Interior (Dualchas 2012)



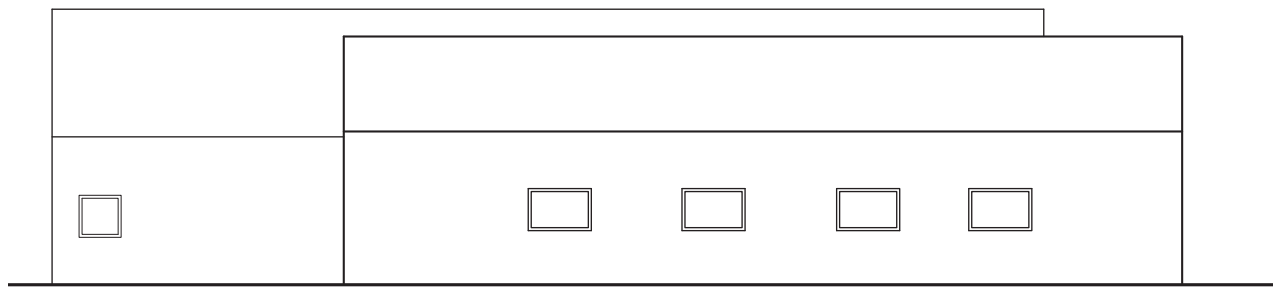
South West Elevation View

North East Elevation View

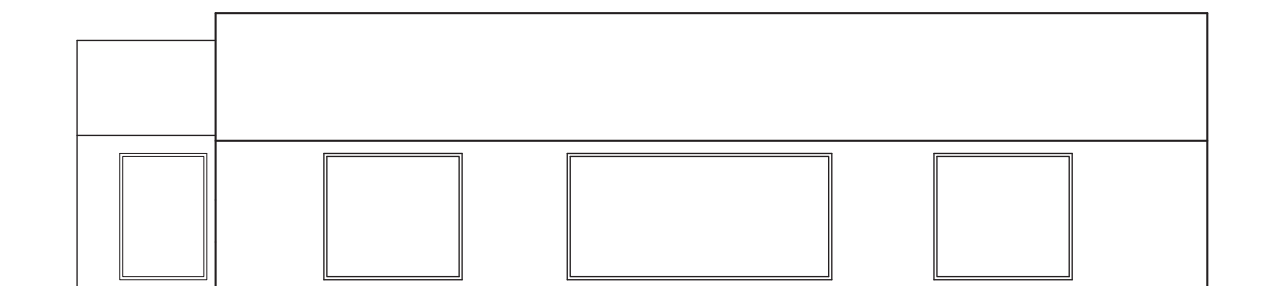


Ground Floor Plan

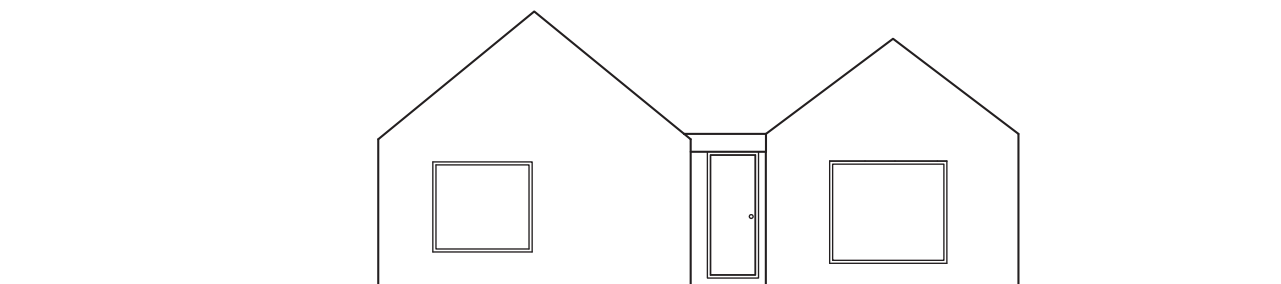
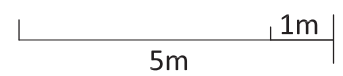
Figure 135- Dualchas, Borerraig Drawings



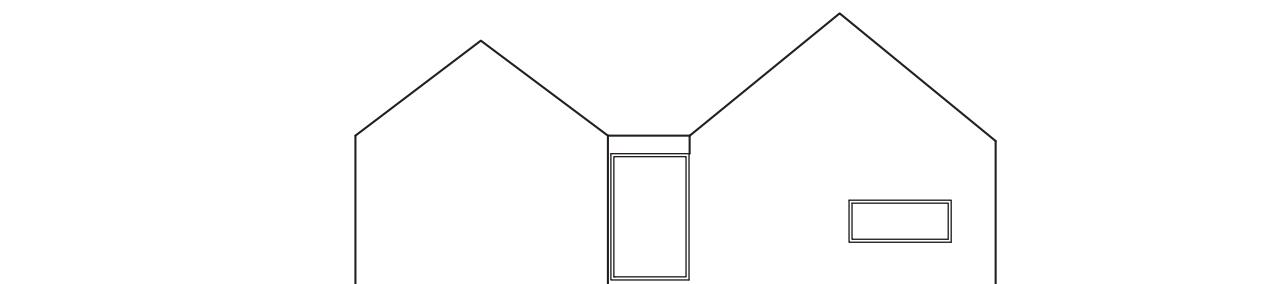
North Elevation



South Elevation



East Elevation



West Elevation

7.1.2. Rural Design, R-House

Rural Design is based on Isle of Skye and was founded in 2002. The majority of their projects are residential and community projects in Scotland. They pride themselves as working “*from new build and furniture-design to landscape and masterplanning*” (Rural Design 2014). They have numerous awards from the Saltire Society, RIAS, RIBA and the Inverness Architectural Association. The firm is mentioned numerous times in the Scottish Government’s Inspirational Designs webpage (St Andrew’s House Scottish Government 2011i; S. A. H. Scottish



Figure 137- Rural Design, Secret Garden House, Scottish Housing Expo

Government 2012d). They were named as Scotland’s Best Practice by Urban Realm in 2013 (Urban Realm 2013b). Rural Design’s placemaking on Skye is described as “*perhaps more profound than the rapid evolution our biggest cities are currently experiencing*” by Urban Realm (Urban Realm 2013b).

Design Approach

Dickson a director of the firm summaries their approach to move away from the recession as “*we need to start by creating well crafted, robust and meaningful architecture, and then get on with the job of communicating the value of good design back to society*” (Urban Realm 2013a). Their approach has been described as a similar but less prescriptive, more relaxed approach when compared with Dualchas (Architecture and Design Scotland (A+DS) & Guest 2011). The overall form of Rural Design Houses take a more sentimental approach that directly references existing rural housing (*ibid*). For example they integrate commonly found accretions such as lean-to’s and outbuilding in their designs. Their Secret Garden House was the first building to be finished in the Scottish Housing Expo which aimed to re-introduce a form of crofting and food production in the walled garden within the plot (St Andrew’s House Scottish Government 2011i). The design could be seen as an interpretation of a traditional cottage which has been developed iteratively over a period of time with different materials and lean to like elements [Figure 137].

Their more relaxed approach is cheerfully illustrated in their competition entry for the



Figure 138- Rural Design Competition Concept

Our Island competition (Rural Housing Service 2014) [Figure 138]. Rural Design describe their approach to be site and client specific, employing a *“crisp and contemporary approach... grounded by an understanding of history and a respect for the environment”* (Rural Design 2014).

R-House

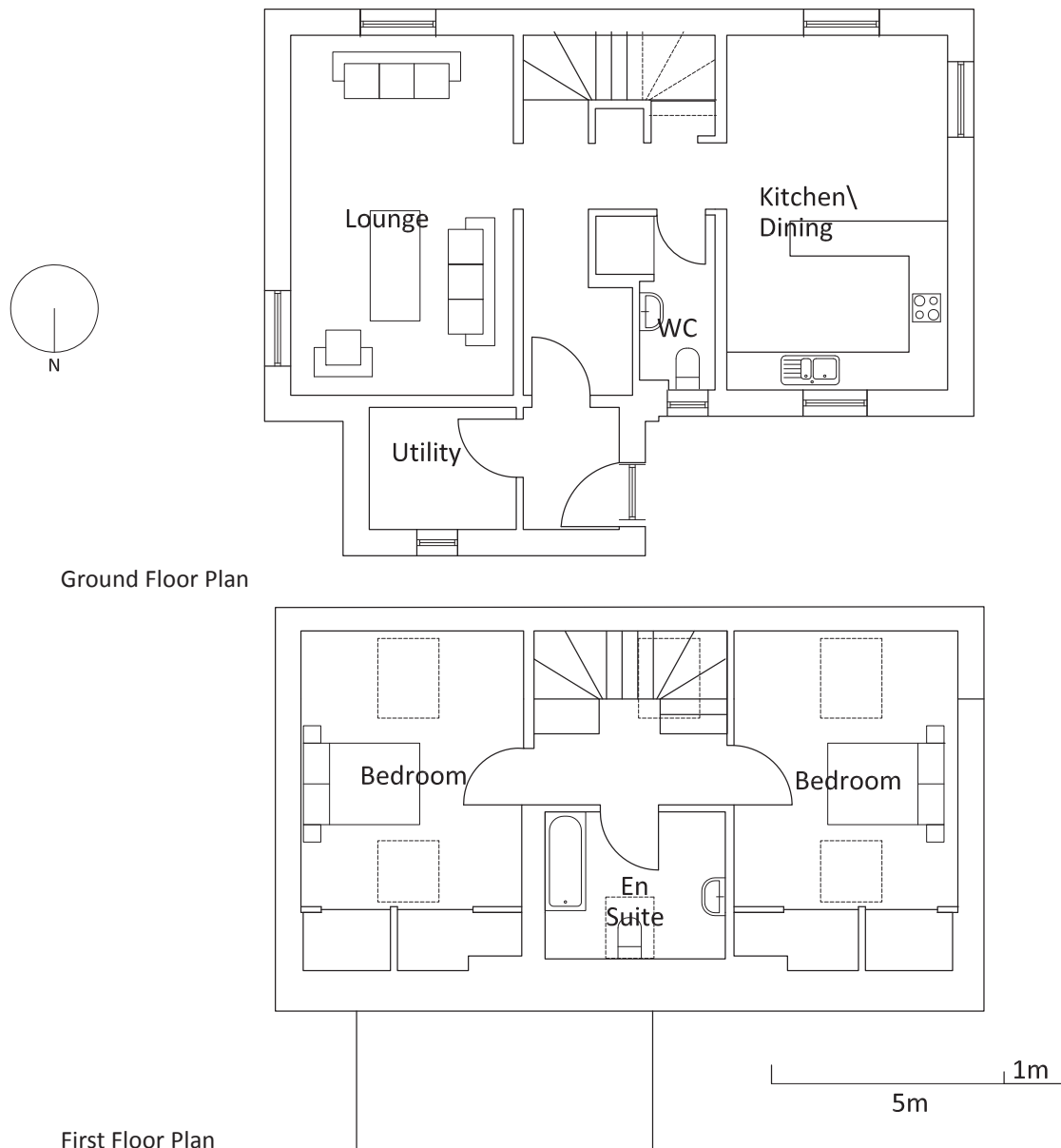
[Figure 139]

[Figure 140]



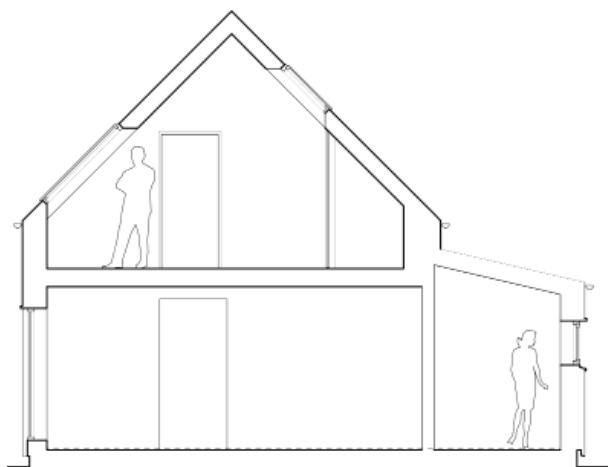
Figure 139- Rural Design R House

The R-House range are simple to construct, prefabricated timber kits designed as affordable homes in the Scottish Highlands which won the Saltire Housing Innovation Award. Rural Design has a sister company that builds and sells the R-House and is a collaboration between director Alan Dickson and builder James MacQueen. The R-house is described as *‘simple forms’* with *‘robust materials’* relating to the *‘traditional Highland barns and steadings with a connection to agricultural forms from elsewhere’* (Scottish Executive 2013f). The house types won the Saltire housing and innovation award in 2012 (BBC 2012a; Saltire Society 2014c). They are designed as a low-cost, off-site constructed timber kit for rural housing available in 1, 2, 3 & 4 bedroom layouts built in a precision assembly facility on Skye (Rural Design 2011; Scottish Executive 2013f). A simple environment strategy is employed; high levels of insulation, a wood burning stove and a whole house ventilation system (Scottish Executive 2013f). They are stated as costing only £300 per annum to heat (Saltire Society 2014c). The R-House modelled in the studies is the two bedroom R2 enhanced variant with an draft lobby and utility room to the rear of the plan. The house cross section uses a one and a half storey type without dormer windows for the upper bedrooms and bathroom. The plan is a modern two version of the historic *but and ben* cottage. The plan is arranged with a central circulation and bathroom block with larger spaces on either side. This creates a rectilinear plan that utilises the roof space for extra accommodation with a minimal amount of circulation. The openings are modest with larger windows to the front of the plan, small openings to the rear and small windows to the sides.

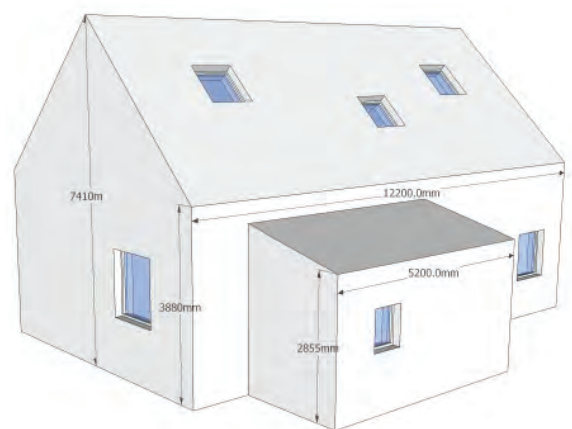


Ground Floor Plan

First Floor Plan

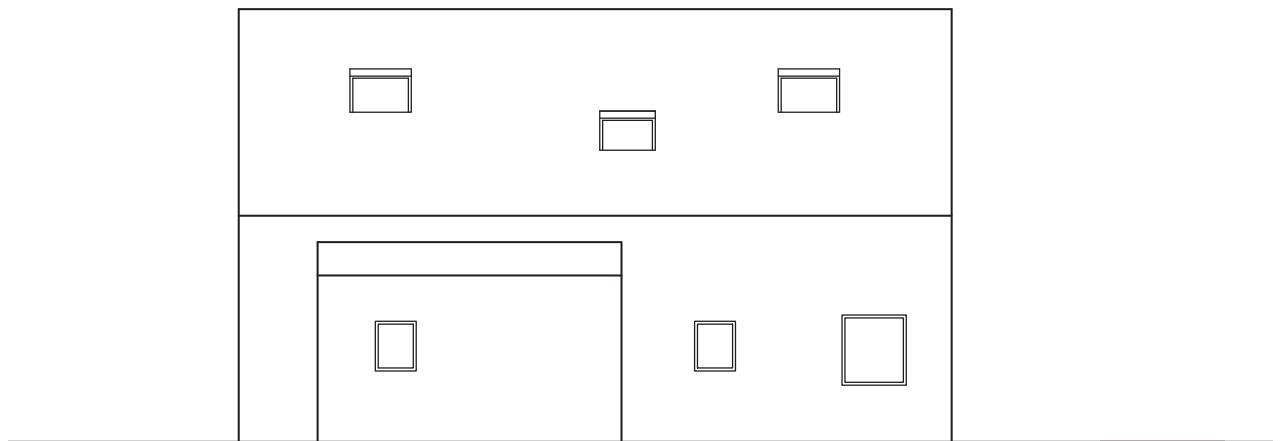


Section

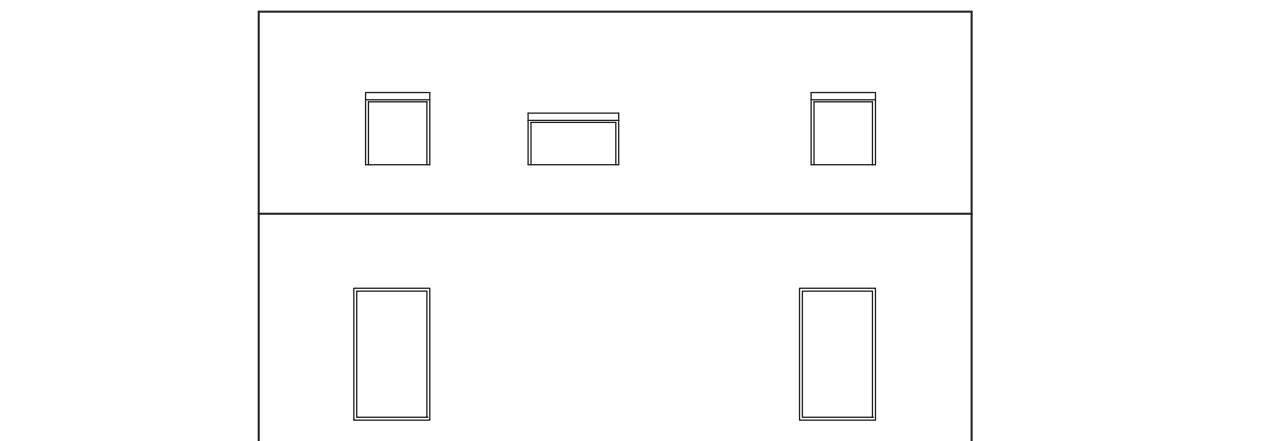


North East Elevational View

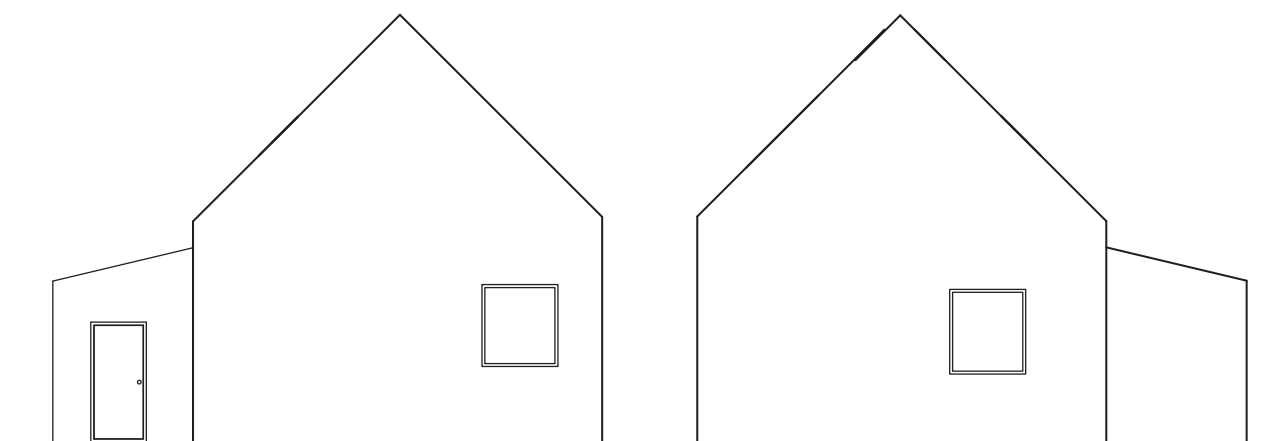
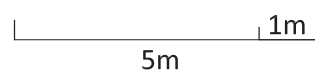
Figure 140- Rural Design R House Drawings (Rural Design 2013) Thanks to Nick Thomson, Rural Design



North Elevation



South Elevation



West Elevation

East Elevation

7.1.3. The Northern Office of Research & Design, Stone House

The Northern Office of Research & Design (NORD) are a Glasgow based firm that was established in 2002 by Alan Pert and Robin Lee (Lowenstein 2012). The practice represented Scotland in the 2004 Venice Biennale and in 2006 they won the Young Architect of the Year Award (Building Design 2006).

Design Approach

Their design approach makes reference to historical forms and uses traditional and familiar materials in new ways. Their contextual responsive approach has been described as a “*working-man’s vernacular*” in comparison to other contemporary architects such as Mole Architecture, Mitchell Taylor Workshop and

Adam Khan (Lowenstein 2012, p.54). NORD have also taken a different approach to the use of vernacular materials. The use of Scottish Caithness stone in their Scottish Housing Fair ‘*Stone House*’ and pared back details creates a strong contrast to the extensive use of finely detailed timber cladding of other Inverness Expo houses (St Andrew’s House Scottish Government 2011i). This interpretation of materials and form sets NORD’s approach apart from other contemporary Scottish architects pursuing a new interpretation of the vernacular (Lowenstein 2012). Pert suggests that the use of timber in new Highland regionalism is “*actually a reaction, therefore expressing something new and modern*” (Lowenstein 2012, p.58). NORD still use timber in their work, but often using alternative interpretations of traditional materials rather than defaulting to timber or white render.

This is demonstrated in the black tarred Shingle House in Dungeness featuring the largest use of shingle worldwide (Dezeen 2010; Scottish Executive 2008c) [Figure 141]. The double pitch timber form of the Tigh Na Gcearc, Linthills house sits on a base course of Portland stone (Pert 2009; NORD 2014a) [Figure 142]. NORD’s Bridge of Dye Steadings illustrate their mixture of the traditional forms integrating modern design elements (S. A. H. Scottish Government 2013a). Both the new and restored sections of the steadings demonstrate regional detailing of the stone and timber.



Figure 141- NORD, Shingle House (Lowenstein 2012)



Figure 142- NORD, Linthills House, Linthills

The Stone House, Scottish Housing Expo

[Figure 143]

[Figure 144]

The Stone House at the Scottish Housing Expo, Inverness is designed as a Gateway Building to the

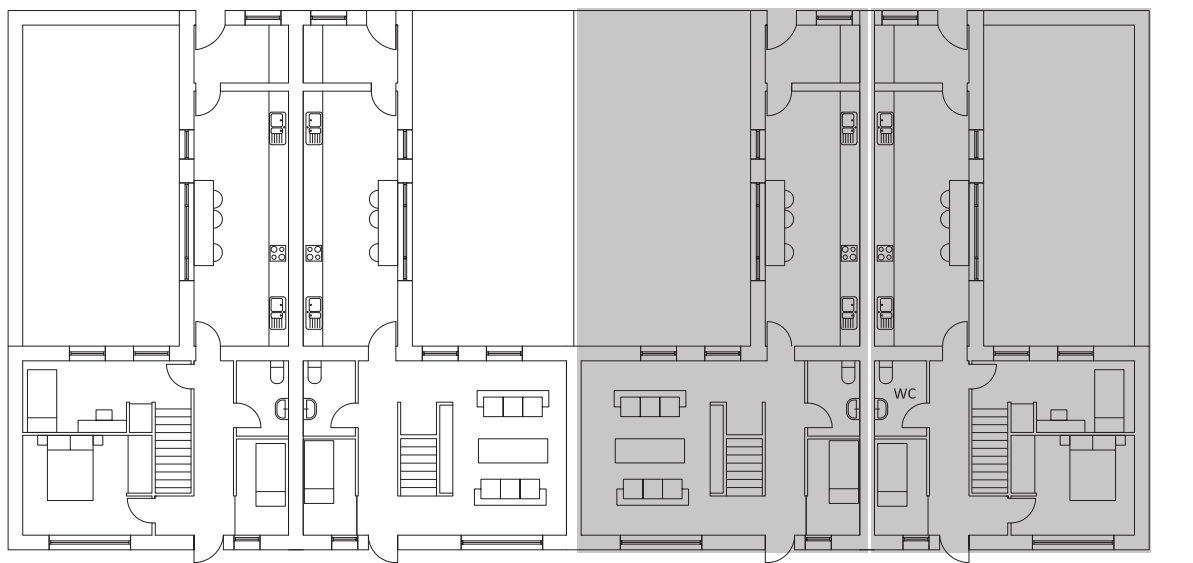


Figure 143- NORD, Stone House, Scottish Housing Expo

development. It's basic iconic form is immediately familiar as a low single storey rural terrace from the front but the deep plan incised by courtyards invents a new 'unfamiliar' rural type. This is further emphasised by the manipulation of the roof of the end terrace dwelling and the two storey east facing glazed opening to the elevated living space producing a dramatic 'urban' entrance corner to the development. The use of stone *"routes (SIC) the building to the site and locates the building in the wider Scottish Landscape"* (NORD 2014b) [Figure 145]. To the rear of the stone façade a black larch cladding is used to surround the private internalised courtyard. The Stone House form references the typical Scottish one and a half storey rural terrace, however it abstracts and simplifies formal elements such as the large side dormer and deeply set openings. It creates an interpretation of an out-building containing functional facilities: pantry, utility, storage, greenhouse, refuse, drying area, and workshop to the base of the courtyard (St Andrew's House Scottish Government 2011i). The intension of the house layout is to focus on the connection between the architecture and landscape creating a public street presence and a private internalised courtyard and upper terrace (St Andrew's House Scottish Government 2011i).



Figure 145- NORD, Stone House, Scottish Housing Expo

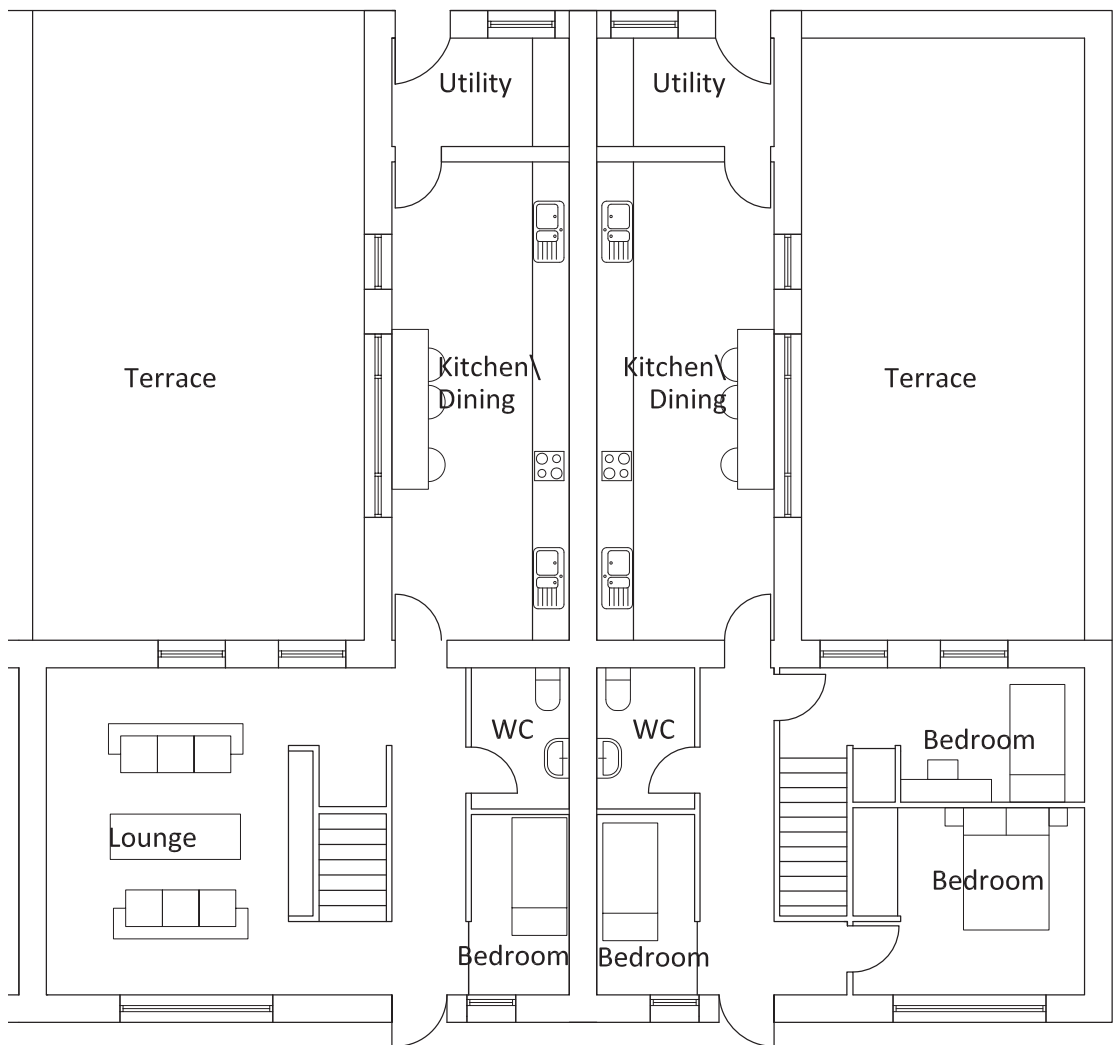


Ground Ground Terrace Plan



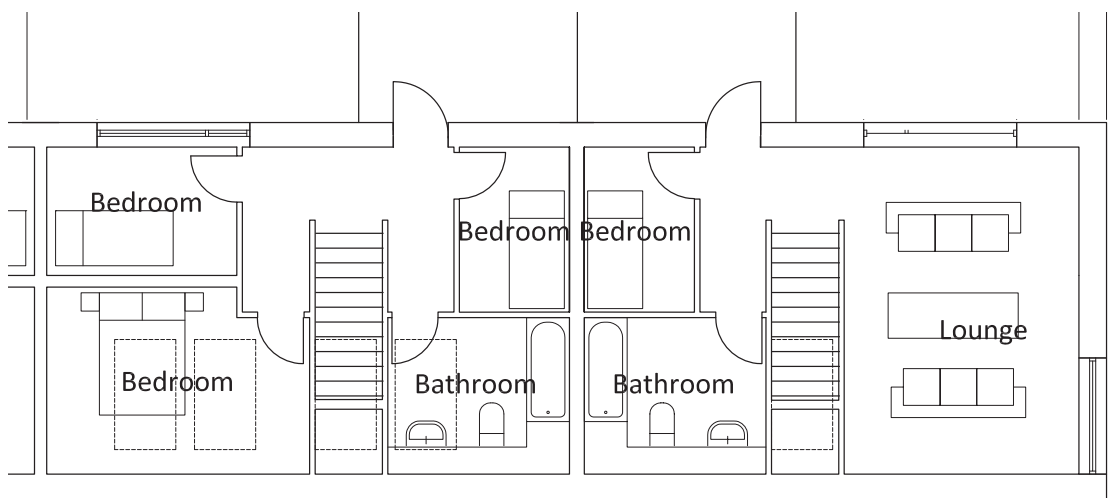
First Floor Terrace Plan

Figure 144- NORD Stone House Drawings



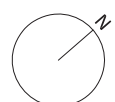
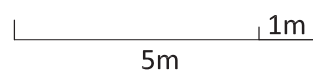
Ground Floor Plan -Mid Terrace

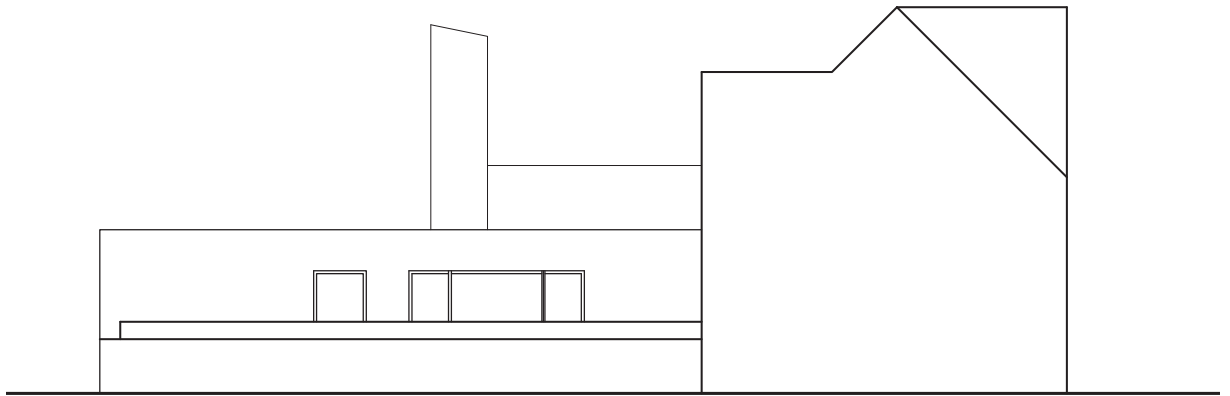
Ground Floor Plan -End Terrace



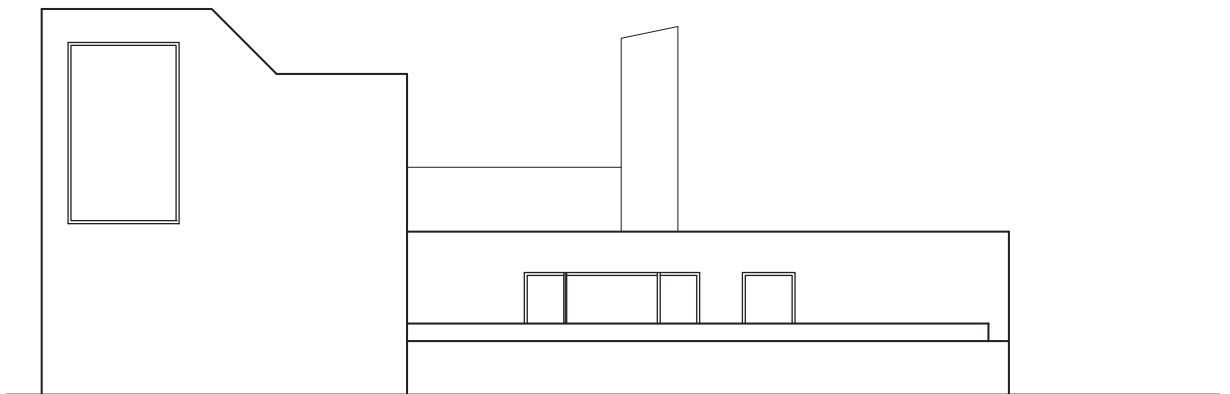
First Floor Plan -Mid Terrace

First Floor Plan -End Terrace

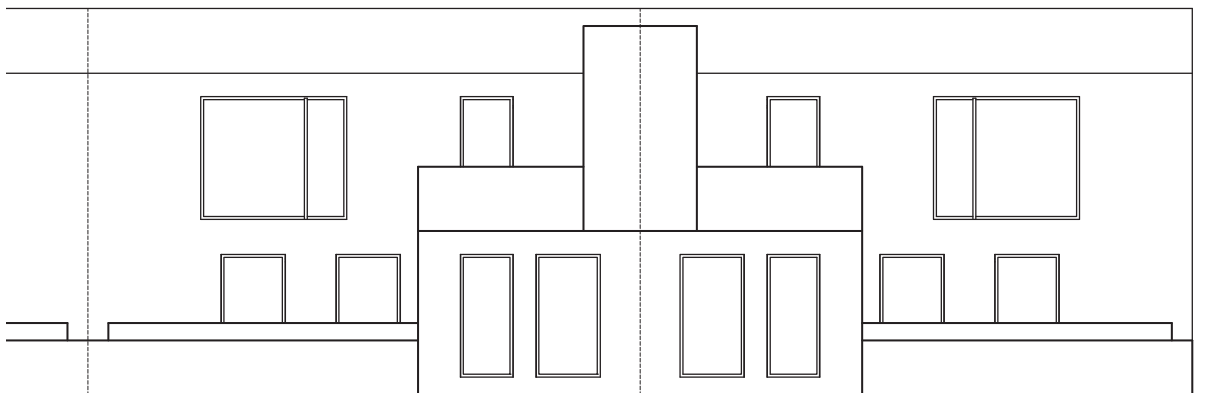




South West Elevation -Mid Terrace

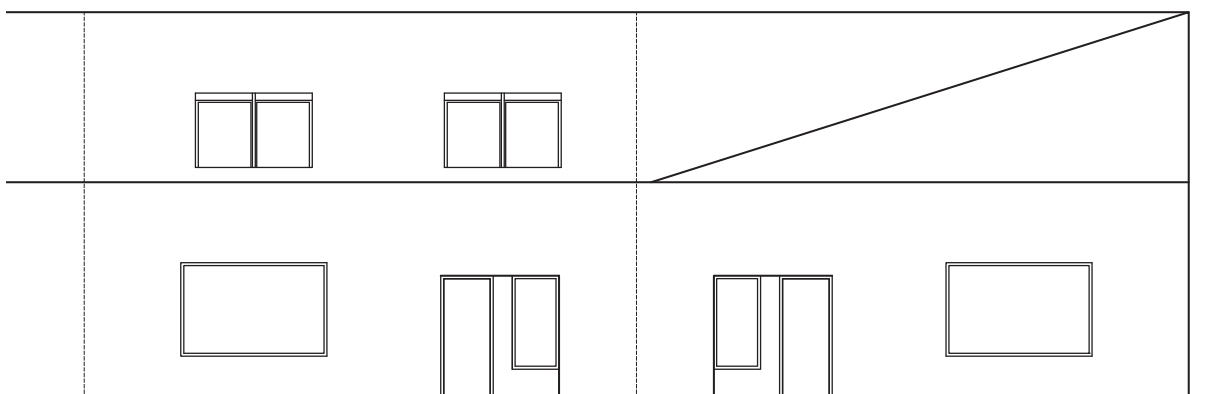


North East Elevation -End Terrace Terrace



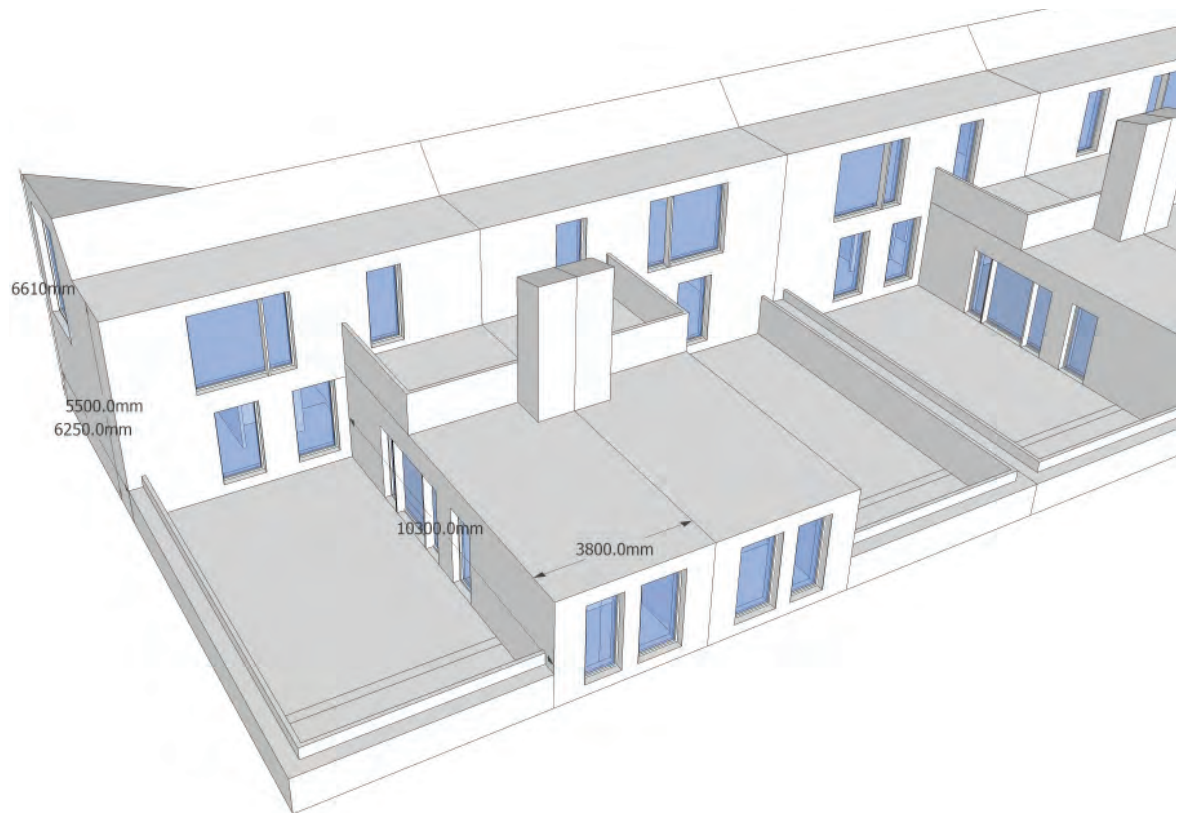
North West Elevation -End Terrace

North West Elevation -Mid Terrace

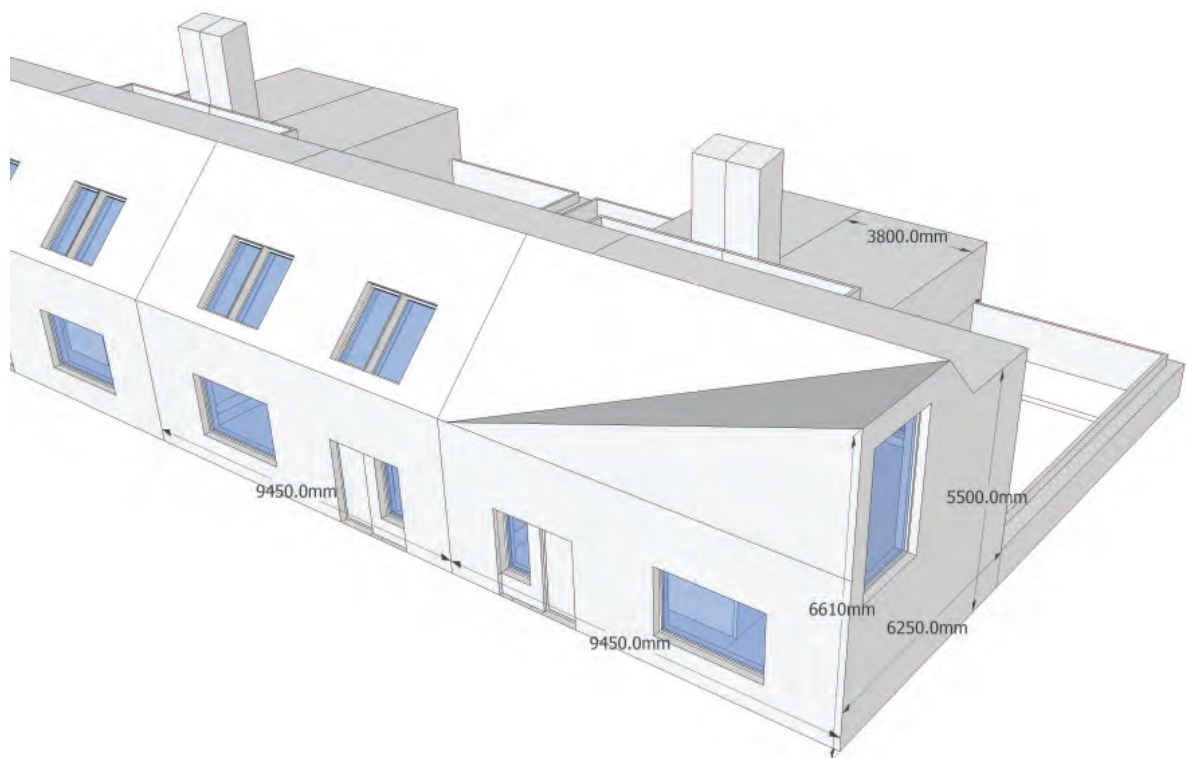


South East Elevation -Mid Terrace

South East Elevation -End Terrace



Mid and End Terrace Rear Elevational View



Mid and End Terrace Front Elevational View

7.1.4. Scotframe

Scotframe is a large scale Scottish timber kit manufacturer established for over 20 years (Scotframe 2013a). They produce timber kits from architects designs as well as having a series of pre-designed timber kits for use throughout the UK and specific rural designs for Scotland which are presented in their *Rural Homes Collection Brochure* (Scotframe 2013b). As part of a kit package they are able to supply many of the components required to build both the external envelope and the internal fittings of the house. Around 85% of Scottish self-build new homes use timber frame construction, with Scotframe supplying the majority of timber kits in this market (Scotframe & Scottish Government 2009). In addition to standard specification timber kits Scotframe also provide Valuetherm timber kits with enhanced performance specification for compliance with future regulations.

Design Approach

Scotframe although not an architectural firm have a collection of pre designed housing designs similar to that of Dualchas Hebridean Homes and Rural Design's R-House. Scotframe's *Rural Homes Collection*, originally released in 1999 is a range of 14 standard kit-house designs developed for rural areas. The intention behind these designs is to give the customer a range of appropriate standardised designs suitable without adaption for a range of needs. The Scotframe designs are designed for clients who do not necessarily wish to have architect designed houses, but want to build in rural areas. The latest designs were presented at *Rural Housing Design Training*, run in conjunction with *Architecture and Place* division of the *Scottish Government* (Lawlor, Architecture+ Design Scotland & Scottish Government 2009). Scotframe's presentation in this event defined key problems that led to the development of the *Rural Homes Collection* (Scotframe & Scottish Government 2009).

- Scotframe are commonly approached by self-builders with no architect who want to build a house in the countryside with no prior knowledge of planning system or 'design' experience (Scotframe & Scottish Government 2009).
- The majority of brochures from kit manufacturers contain suburban style housing models.

The design of Scotframe's Rural Homes refer to the current planning guidance and advice notes, discussed in 3.2.2.5. The current brochure of Rural Homes also contains guidance for siting and landscaping of their house types addressing the importance of



Figure 146- Tulla House Type (Scotframe 2013b)

good quality design combined with and good place making (Lawlor, Architecture+ Design Scotland & Scottish Government 2009).

The brochure illustrates the designs with simple plans and a water colour style renderings. The designs range from a 67m² two bedroom to a 182m² four bedroom variant. These designs take reference of existing rural homes and features. The reinterpretation of existing designs and style results in designs with small areas of glazing with little thought to solar gains. The plan layouts generally reflect typical suburban designs that have large areas of circulation and complex internal layouts. Some of the larger designs feature complex volumetric arrangements which reference the form of traditional houses which have seen multiple extensions. This leads to high exposed surface areas, convoluted internal planning and a large number of complex junctions [Figure 146].

Scotframe Clousta

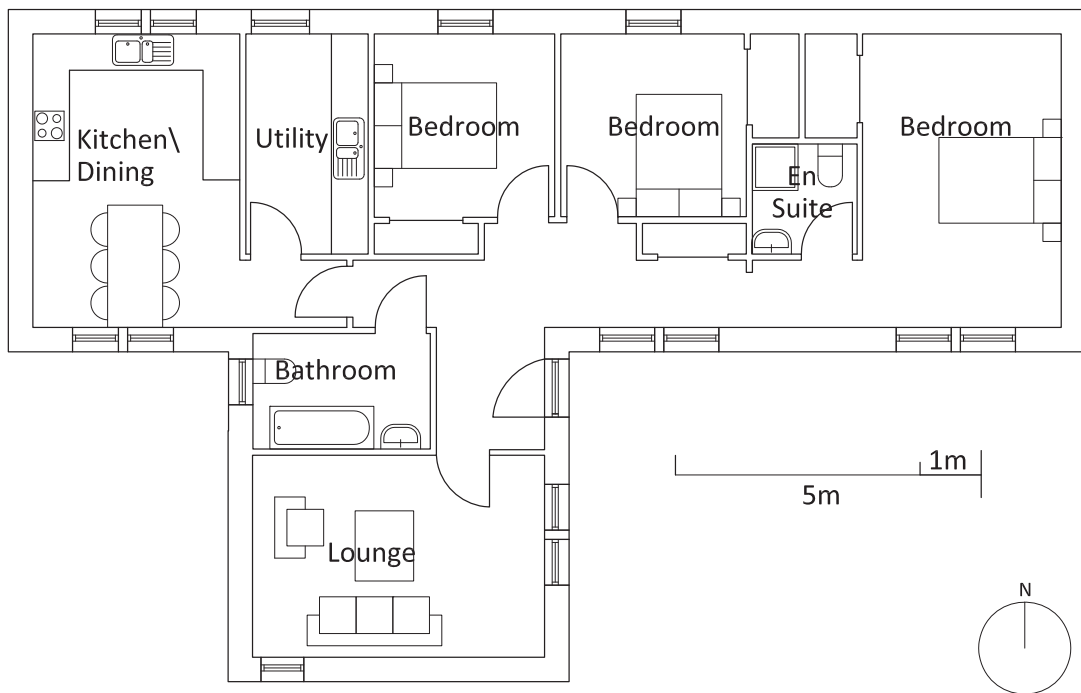
[Figure 147]

[Figure 148]

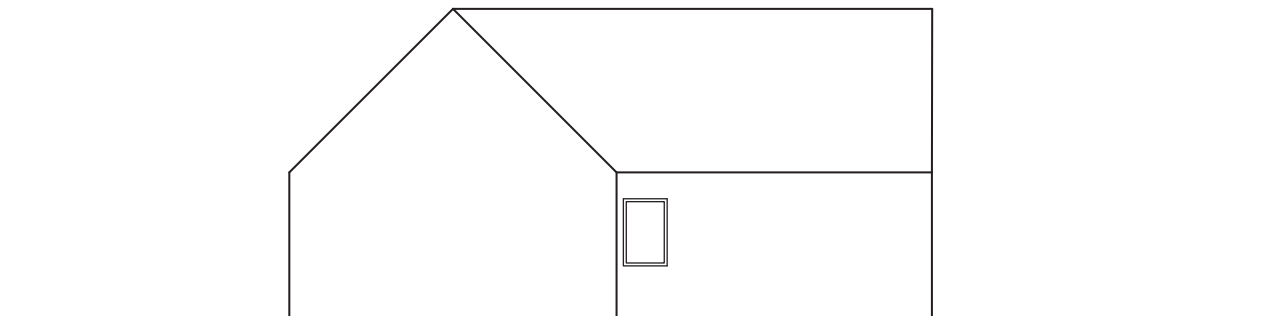
For the *Optimisation Study* the Clousta housing design is identified from the brochure. The Clousta is a typical 106m² three bedroom rural house type. It is a single storey bungalow with the accommodation arranged in a 'T-Shaped' plan layout. Scotframe only describe a general introduction to the collection of designs rather than individual descriptions. The Clousta appears to reference the form of an extended single storey white house layout. All of the bedroom accommodation runs across the rear of the plan with the lounge and bathroom to the front half of the plan. The plan depth is around 5.6m which references the scale of traditional models. The openings are similar sizes distributed in all directions. Therefore the design does not appear to have a set orientation that responds to solar gain to allow for flexible site arrangement options.



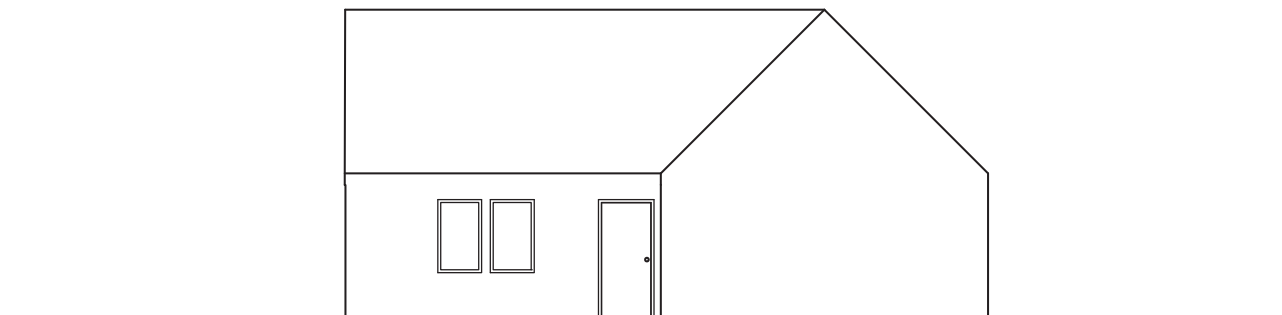
Figure 147- Scotframe Clousta House (Scotframe 2013b)



Ground Floor Plan

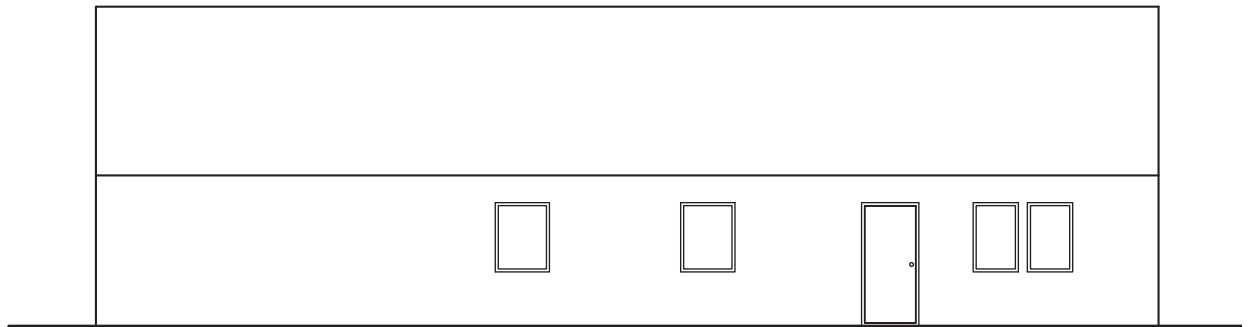


West Elevation

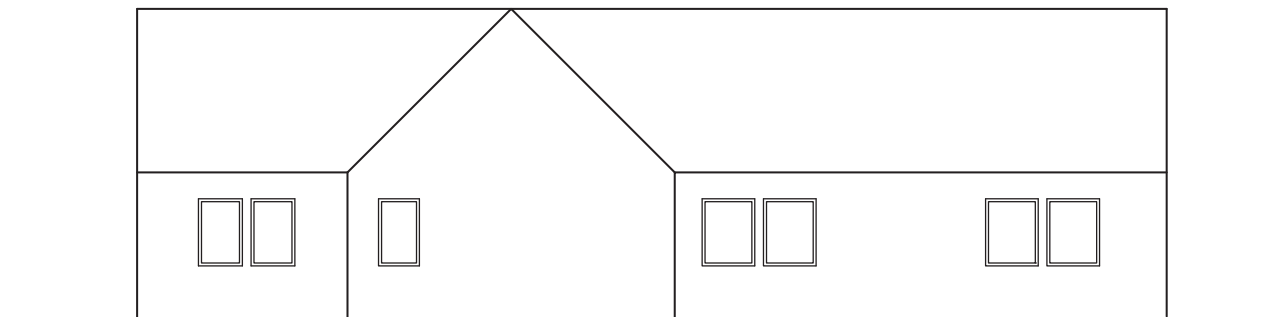


East Elevation

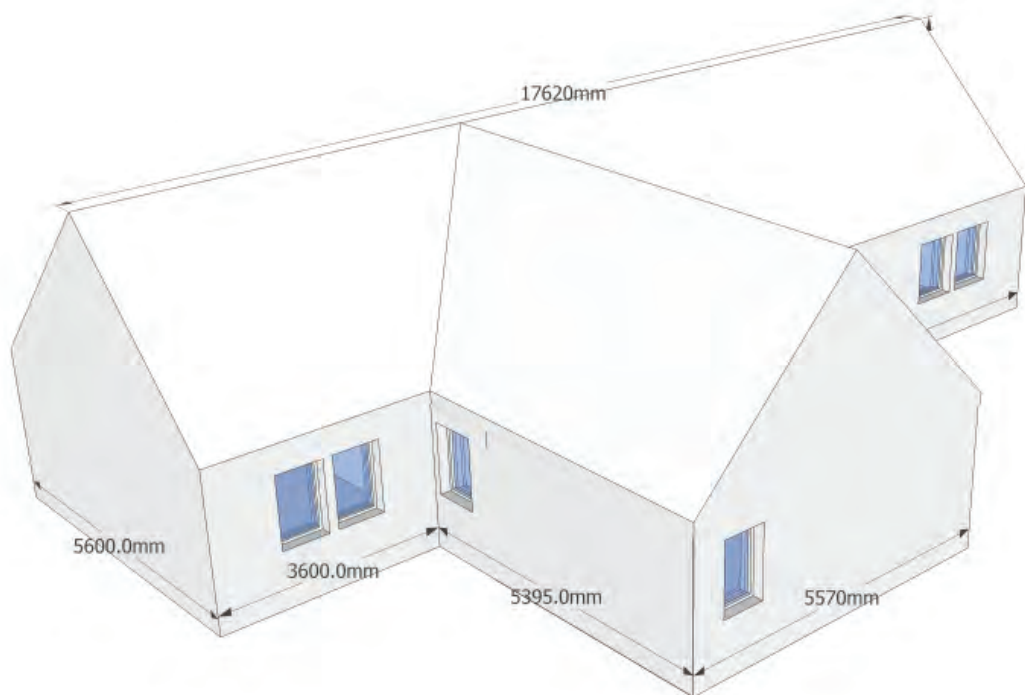
Figure 148- Scotframe Clousta Drawings



North Elevation



South Elevation



South West View

7.1.5. Scotframe & Proctor & Matthews Outer Hebrides Kit House Study

Outer Hebrides Kit House Study

was a timber kit re-design exercise in collaboration with Proctor & Matthews, Comhairle nan Eilean Siar and Scotframe (St. Andrew's House Scottish Government 2011a). The intention was to create a portfolio of designs that related to the past but respond to a modern way of life for the Outer Hebrides (Scotframe 2013b).



Figure 149 Polnoon (Proctor and Matthews 2014)

Proctor & Matthews are a London based firm that were founded in 1988. The practice has received more than 40 international design awards. Much of the key work from the practice are large scale modern developments cited across the world ranging from masterplanning to sports and arts buildings (Proctor and Matthews 2014). Proctor & Matthews also have a limited number of smaller projects featured on their web site and were responsible for the Polnoon re design project, discussed in 3.3.3 [Figure 149].

Design Approach

Scotframe, Proctor & Matthews Architects and Comhairle nan Eilean Siar performed a kit house re-design exercise which was endorsed by the Scottish Government. The concept of the Outer Hebrides Kit House Study project was to create a new portfolio of houses which are more in-keeping with Scotland's rural vernacular (Scotframe 2013b). The key aim defined by the Government was *"to design an appropriate 'kit house' which will embrace the aspirations of 21st century lifestyles with an attention to scale and sensitivity to context"* (St. Andrew's House Scottish Government 2011a). The study was a part of the *Rural design: Future Landscapes* initiative run by the Scottish Government from 2009 to 2011. The redesign was developed in tandem with and to follow the *Outer Hebrides Design Guide* (Comhairlie nan Eilean Siar 2010).

The design process started with an analyses of the different house types found in the Outer Hebrides including

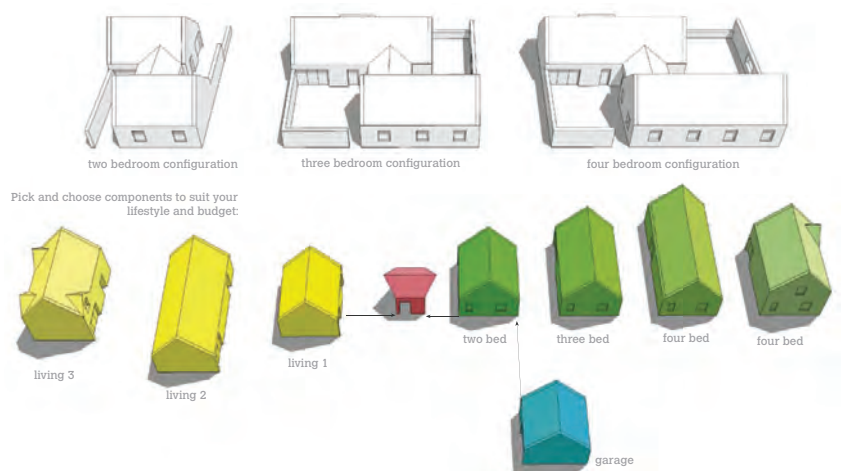


Figure 150- Outer Hebrides Kit House Study Design Components (St. Andrew's House Scottish Government 2011a)

the Blackhouse, white house and the DAF house. In addition to the building form the study considered the existing placement and landscape features of the exiting types. The re-designs concept created a courtyard cluster of small elements that can respond to a variety of traditional layouts found in the Outer Hebrides. The concept for a new housing model was based on a clustered arrangement of simple building forms organised in courtyard layout and connected along the perimeter with low walls to produce a simple contained footprint within the landscape. The design therefore comprised a series of simple volumes containing different elements of the programme that could be arranged flexibly to accommodate different contexts, orientations, topography and living arrangements [Figure 150]. There are a series of key design moves that apply to all of the designs (St. Andrew's House Scottish Government 2011a):

- Uncomplicated roof forms
- Standardised roof trusses
- Extended perimeter wall area
- Simplified fenestration
- Enclosed protected courts/yards

The designs all consider the living component and sleeping component as two separate elements with a joining entrance link and separate garage. This creates a form similar to Dualchas' Boreraig house.

116m² Study House

[Figure 151]

The optimisation study considers the two bedroom with garage (116m²) variant as the other designs have larger footprints and higher exposed surface area which may cause issues when comparing results. The example is perpendicular to the street with courtyard entrance [Figure 152]. The house is the smallest of a series of examples based on a 17m wide plan with varying

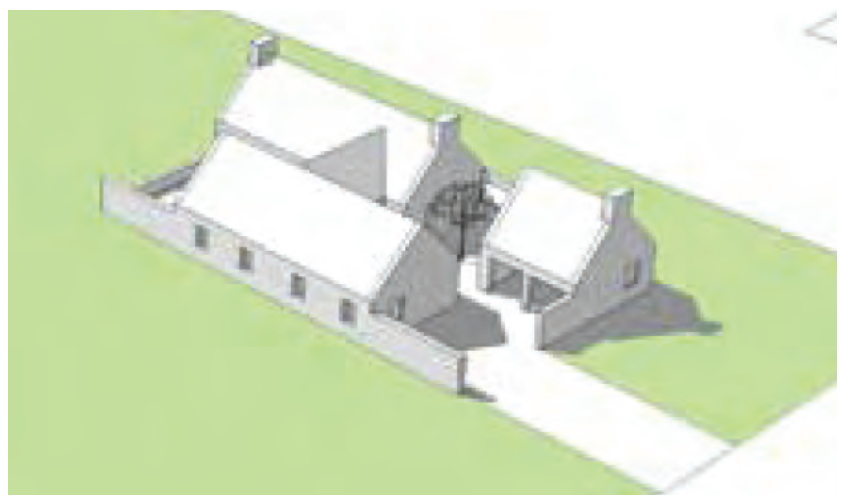
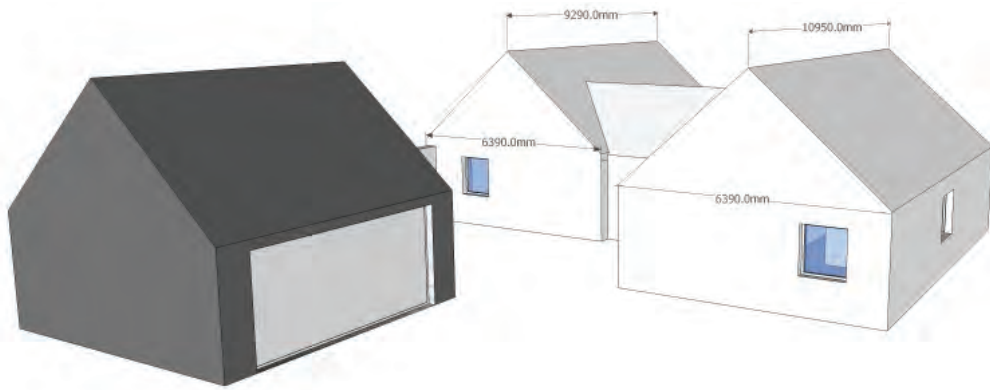
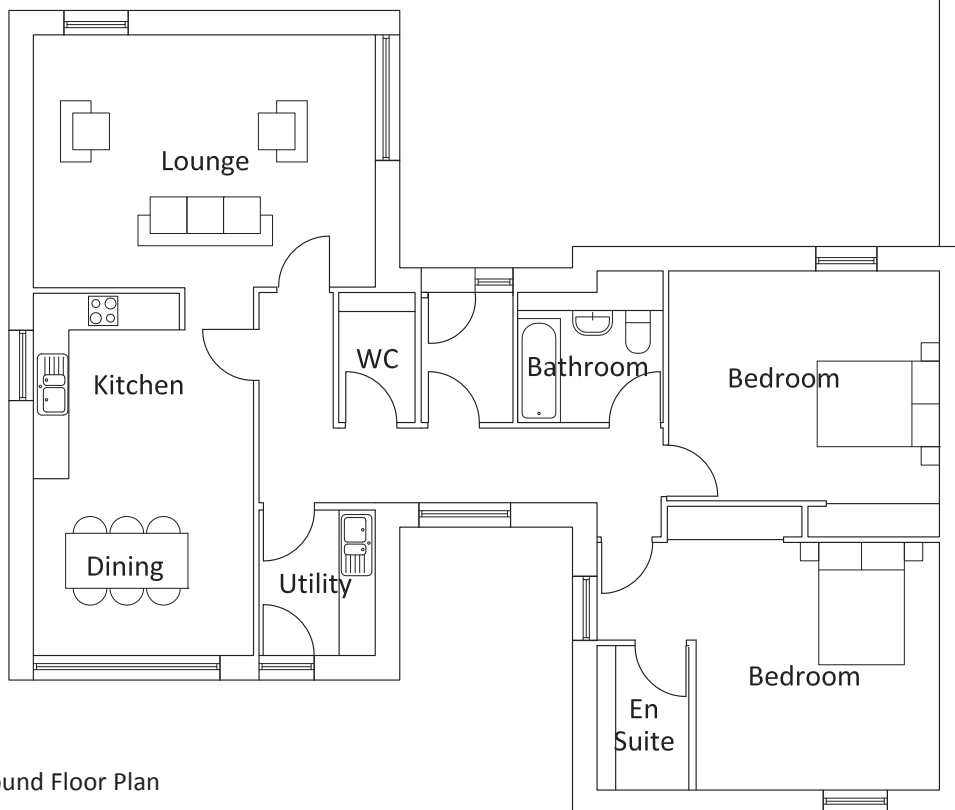
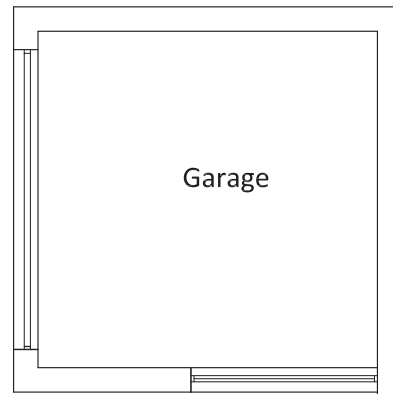
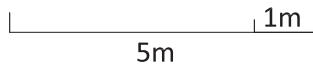
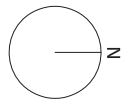


Figure 151- Outer Hebrides Kit House Study Model Image (St. Andrew's House Scottish Government 2011a)

length therefore it will fit into narrow lotted land parcels traditionally associated with traditional crofting land layouts (St. Andrew's House Scottish Government 2011a). The plan layout is split across two main blocks with a joining hallway and bathroom. The design has one block with two bedrooms with the second block containing the dining, kitchen and living room. The design has no clear orientation that is designed around passive solar gain principles.

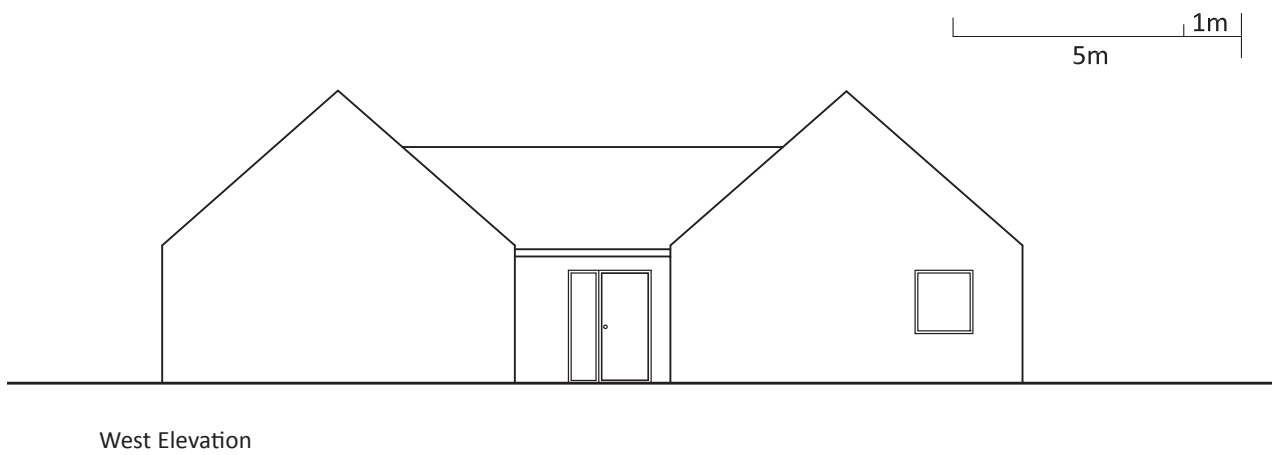
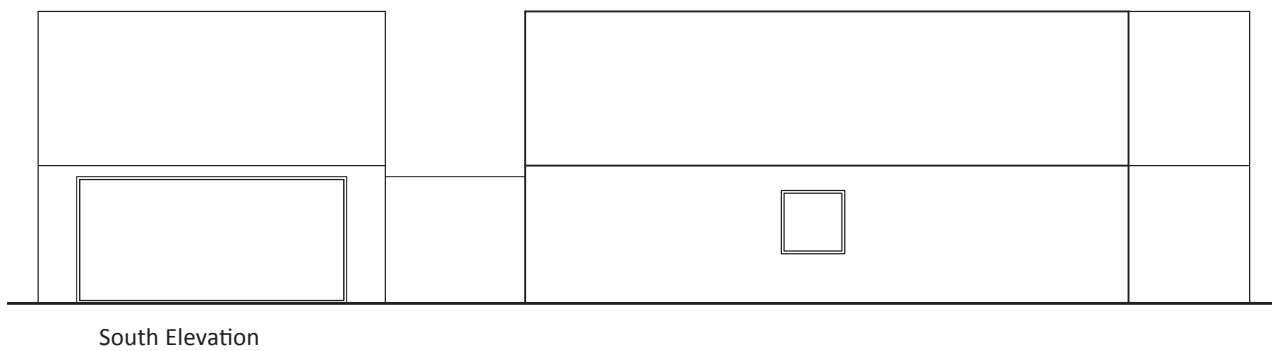
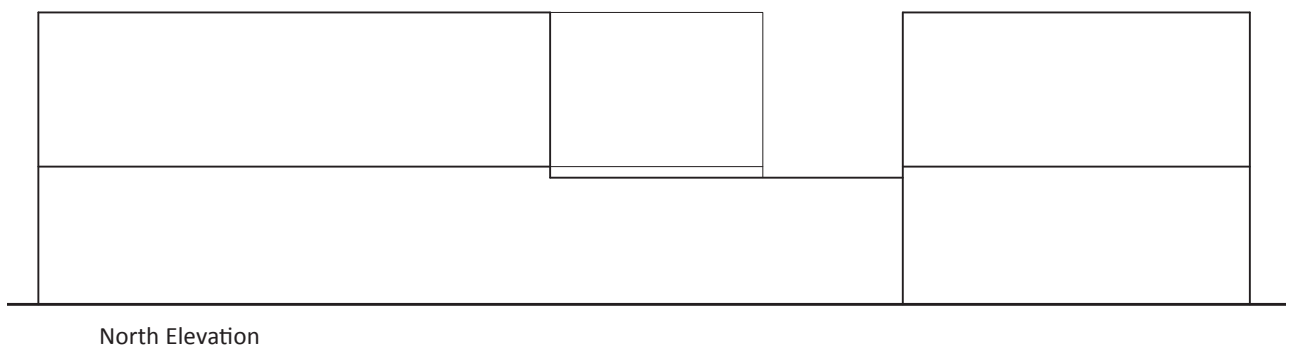
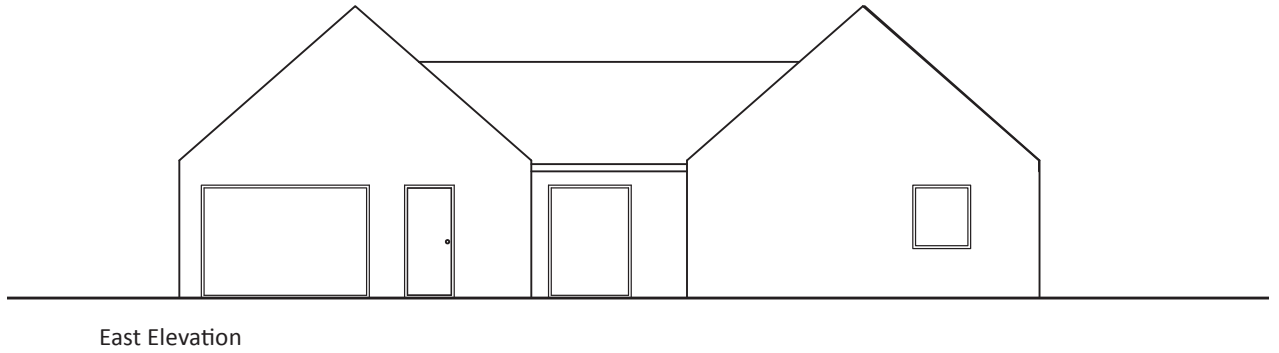


North West View



Ground Floor Plan

Figure 152- Proctor Mathews & Scotframe House Drawings



7.2. Analysis and Optimisation Study Methodology

7.2.1. PHPP Data Input And Output Changes

Technical Improvements to customised PHPP input/output Spread sheet

Due to the increased complexity of the study, various improvements to the customized PHPP user input were made to simplify the data input. Use of the customised PHPP file in practice also led to improvements on window input and more specific on site optimisation. The main improvements fall into two categories; expansion to data input controls and quicker, more accurate input of different design models.

Building Fabric Metric Inputs

[Figure 153]

- The window input is expanded from two window types to four
- The input for horizontal (roof lights) is extended to include four window types with individual inclination angle inputs to allow for windows on differently angled roof planes. In some cases roof light orientation is linked with window orientation so values update automatically.
- Additional fine grain orientation inputs for exact orientation for modelling buildings on-site characteristics quickly. This pull down list contains all common orientations in 10 degree increments with an option to add specific entries.
- Additional control of U-Value input that allows for the user to use a pull down menu to select the relevant climate data region, this allows for the selection of the relevant weighted u-value for the climatic region and then alters the thermal specification of each of the separate climate region PHPP calculation files.
- Additional control over airtightness rates and MVHR switch.
- Improved control over shading both for window reveals and temporary summer shading

Quick Building Input Method

A pull down list was developed to allow complex building metrics to be entered simply and more accurately. This allows the user to quickly switch between the full range of models stored on a different Excel sheet within the input document which reduces the margin for error as building metrics are entered once. The following Excel formula is one example developed for the research by the author for efficient building metric data input. The formula allows the building metric input data to be referenced from the typology inputs sheet with relative cell referencing.

- `=IF(INDIRECT("'"&Typology inputs!'&ADDRESS(ROW(),C2+COLUMN()-COLUMN(INDIRECT("c1"))))=""", "", INDIRECT("'"&Typology inputs!'&ADDRESS(ROW(),C2+COLUMN()-COLUMN(INDIRECT("c1"))))`

Inputs Areas

Scotframe Clousta SSDH

	173 (8 Norm 18 party)		
Floor	102.94		
North Wall	44.05	8.00	
South Wall	52.02	8.00	
East Wall	35.36	8.00	
West Wall	35.33	8.00	Perimeter
Floor Slab	128.74		57.24
Roof	182.29		
party Wall Roof WEST			
party Wall Roof EAST			

House Study Input

Scotframe Clousta SSDH	
------------------------	--

Windows

	Width	Height	No	Dev	Nrth Area	Angle from North	Area (m2)	% Area of Surface
North Windows	0.75	1.05	2	1	North=1	0	1.575	4.46
	0.95	1.05	1	1		0	0.9975	
	0.9	1.05	2	1		0	1.89	
	0	0	0	1		0	0	10.13%
East Windows	0.75	1.05	2	3	East=3	90	1.575	1.58
	0	0	0	3		90	0	
	0	0	0	3		90	0	
	0	0	0	3		90	0	4.45%
South Windows	1.3	1.05	4	2	South=2	180	5.46	18.60
	0.9	1.05	2	2		180	1.89	
	4.5	2.5	1	2		180	11.25	
	0	0	0	2		180	0	35.75%
West Windows	0.75	1.05	1	4	West=4	270	0.7875	0.79
	0	0	0	4		270	0	
	0	0	0	4		270	0	
	0	0	0	4		270	0	2.23%
Horizontal Windows	0	0	0	0	Roof=6	270	0	
	0	0	0	0			0	
	0	0	0	0			0	
	0	0	0	0			0	
Door	0.9	2.1	1		roof angle ^	0	Deviation from South	

Volumes

Enclosed (Gross Volume) ent	539.2
Ventilation Volume	257.3425
Airtightness Rate	0.6

Occupants

Occupants	4
-----------	---

Ventilation

Summer Ventilation

Air Change by Natural	1.49
Night Ventilation	1.49
Mechanical	0.3
MVHR ON(=x)/OFF	x

U-Values

	Thickness	
Walls	0.091	45
Roof	0.091	45
Ground	0.151	27.6
	g-Value	Ug- Value
Glazing	0.52	0.61
	Y-Spacer	Uf- Value
Frame	0.043	0.63
Door		0.81

Ground

Joess House Temp

Insulation W/D	0.71
Thickness	0.1
Thermal Conductivity	0.02 W/(mk)

Shading

	South	East+West	North	Horizontal
Reveal Depth	0.2	0.2	0.2	0.2
Glaze to Reveal	0.05	0.05	0.05	0.05
Overhang	0.2	0.2	0.2	0.2
Glaze to Overhanh	0.05	0.05	0.05	0.05
Add	100%			
Temp Summer Shading	50%	100%	100%	100%
Overheating West of Scotland				0

Airtightness PH to UK

PH Mandatory	0.6 ac/h @50pa
Scottish	10m3/h.m2 @50Pa
CSH	6m3/h.m2 @50Pa

ac/h to m3/h.m2

AT CURRENT AT TEST

102.94 m2

539.177002 m3

323.5062012 m3/h

@50Pa air change

m3/h.m2 to ac/h

Presume 1 m3/h.m2 @50Pa

102.94 m3/h @50Pa air change

1 m3/h.m2 @50Pa

0.1909 ach @50pa

U-Values to Counteract ACH

0.2 Air Ch: 0.6 Air Change

0.12	0.11
0.12	0.11
0.13	0.13

	Monthly	Annual	Heat Load	Losses Gains
East Scotland 16	15.367	15.067	10.261	
Specific Space Heat Demand, UK Average Climate				
Specific Space Heat Demand, Orkney 20	18.954	17.924	12.939	76
Specific Space Heat Demand, West Scotland 15	22.887	21.662	10.931	57.5234595
Specific Space Heat Demand, UK Average 0	13.964	13.349	9.166	71
Specific Space Heat Demand, Orkney 20				48.16095874
Specific Space Heat Demand, UK Average 0				61
Specific Space Heat Demand, Orkney 20				47.33098654

Detached Study

Custom Entry	0.11	W/(m2K)
Orkney 20	0.091	W/(m2K)
West 15	0.157	W/(m2K)
East 16	0.149	W/(m2K)
UK Average 0	0.13	W/(m2K)

Climate Data Input:

Orkney 20

% Change Calculator

From (large)	22.68371	6% less
To	21.25167	

Varation

High	25.616	24.705
Low	25.53531	22.887
	0.081	1.818

Figure 153- Finalised Input Sheet Chapter 7

Limitations to Customised Spread sheet

A limitation of the input and results page is the separation between south facing windows and south facing roof lights. It was found that PHPP does not differentiate between the two. Therefore the results output which generates a percentage of glazing on the south elevation is incorrect. Additionally when the orientation of windows are altered the surface area percentage of openings becomes incorrect. Windows in PHPP are not linked to the wall location and walls do not have a defined orientation. This has little effect to the accuracy of the results as the variation between heat losses and heat gains of walls across different orientations are negligible.

7.2.2. Standard Technical Specification

Variable Technical Specifications

In Chapter 6 it was shown the extent to which the SSHD of a standard prototype house varies across the different climate data regions. In this study weighted U-values obtained from the study 1B optimised for the different climate data regions are used for the seven exemplars in the extreme Scottish climatic regions. The use of weighted U-values will allow for the direct comparison of the performance between different building designs/forms in relation to the ULEH compliant prototype specification in the regional climates. The increase or decrease in SSHD and heat load are then easily assessed against the compliance SSHD benchmark for ULEH of 15 kWh/(m²a) or 10 W/m².

The wall and roof u-values associated with each of the regions for the detached housing study are as follows:

- Orkney: 0.091 W/(m²K)
- West of Scotland: 0.157 W/(m²K)
- UK Average 0.132 W/(m²K)

The following weighted u-values are used for the mid terrace models to achieve 15 kWh/(m²a).

- Orkney 0.137 W/(m²K)
- West 0.234 W/(m²K)
- UK Average 0.194 W/(m²K)

The following weighted u-values are used for the semi-detached models to achieve 15 kWh/(m²a).

- Orkney 0.11 W/(m²K)
- West 0.188 W/(m²K)
- UK Average 0.156 W/(m²K)

Constants

The data entry for this project share the constants from the previous study which use typical Passivhaus specifications and technology suitable for Scotland. This includes glazing and the use of an MVHR unit with a

building airtightness of 0.6 ach/h-1.

Climate Data

The range of climate data sets used illustrate the best and worst cases across Scotland with Orkney having the highest SSHD and the West of Scotland the lowest SSHD.

7.2.3. PHPP Data Entry Assumptions & Limitations

Limitations of Data Entry

Due to the limited availability of drawings and building complexity the PHPP models used to analyse the building types have been simplified eg. for the Scotframe Clousta and Outer Hebrides improved rural house type window dimensions had to be estimated from scaled images of the designs.

Area discrepancies

The method to measure floor area creates discrepancies between the PHPP input and the designer state areas. This is due to the PHPP input method not including partitions or stairs and only including a half area for spaces with a height between 1 and 2 meters (Passivhaus Institut 2007).

Window Data Entry

The window data input was simplified to a single area of glass and omitted internal mullions. A result of this is that multiple section windows will appear more efficient in the PHPP calculation due to the reduced amount of heat loss around the frame which is the most inefficient part of a window. However, this was not considered to be a major factor influencing the comparison of building form and was omitted from the calculations.

House Design Variables

[Figure 154]

The use of the customised PHPP spread sheet allows for the input of the variables used in the study to be simplified compared to the use of the standard PHPP calculation. The full design envelope can be entered into the Spread sheet using a simplified number of inputs. The variables for the different housing designs can be categorised into the following groups which reflect the customised PHPP input sheet:

- Floor Areas
- Wall Areas
- Part Wall Areas
- Ground Slab area and perimeter
- Window sizes, orientation and quantity
- Roof window sizes orientation and quantity

Inputs Boreraig					
Areas					
Floor	127.2693				
North Wall	45.80907	8			
South Wall	47.80268	8			
East Wall	33.98753	8			
West Wall	33.98753	8	Perimeter		
Floor Slab	157.8162			60.7	
Roof	198.783				
party Wall	Roof WEST				
party Wall	Roof EAST				
Windows					
	Width	Height	No	Dev	Nrth
North Wind	1.05	0.7	4	1	
2	0.5	2.1	1	1	
3	0.7	0.7	1	1	
4	0	0	0	1	
East Wind	1.65	1.5	1	3	
2	1.95	2.1	1	3	
3	0	0	0	3	
4	0	0	0	3	
South Wind	2.3	2.1	2	2	
2	4.4	2.1	1	2	
3	1.45	2.1	1	2	
4	0	0	0	2	
West Wind	1.7	0.7	1	4	
2	1.3	2.1	1	4	
3	0	0	0	4	
4	0	0	0	4	
Horizontal	0	0	0	6	
	0	0	0	0	
	0	0	0	0	
Door	0.925	2.2	1		
Volumes					
Enclosed	510				
Ventilation	318.1732	318.1732			
Airtightnes	0.6				

Figure 154 Customised Input Method

- Door Sizes and quantity
- Volume- gross and ventilation

Climate Data

- Orkney
- West of Scotland
- UK Average Climate

7.3. Study 1: Comparison of Existing Design Performance

Each of the designs were entered into PHPP and analysed using the three different climate data sets namely: Orkney, West of Scotland and the BRE UK Average. This provides basic information such as the SSHD and heat load (HL). The study simply compares the house types SSHD and heat loads in relation to each other and to the PH prototype. Because the Scotframe Clousta, Scotframe/Proctor Matthews and Rural Design R-House do not have defined site locations or orientations, consequently it was assumed that the living space would be orientated due south. This is annotated on the drawings. The NORD and Dualchas schemes are orientated as per the built example. The PH prototype retains its original orientation with the principle elevation facing south. The NORD stone house detached model is a hypothetical study on the implications of the viability of taking an end terrace model for use as a single house.

House Designs

Control





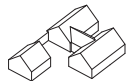
- Prototype Detached House
- Prototype Semi Detached House
- Prototype Terrace

Exemplars


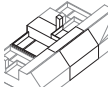
[Figure 155] Building Metrics

- Dualchas, Boreraig
- Rural Design. R2 House
- Scotframe, Clousta
- Proctor and Matthews Architects ,Outer Hebrides Kit Study Prototype
- NORD, Stone House Detached House End Terrace Model)
- NORD, Stone House End Terrace
- NORD, Stone House Mid Terrace

Detached House Type Metrics

Prototype:	Control Detached	Boreraig	Rural Design R2	Clousta	Outer Hebrides
					
Areas					
Floor Area m2	107.0	127.3	118.7	102.9	114.4
Volume m3	508.0	510	522.9	539.2	555.7
Volume (Ventilation) m3	268	318	297	257	286
Area/ Volume Ratio (Gross) m2/m3	0.73	1.02	0.81	0.89	0.95
Exposed Surface Area m2	371	520	422	480	527
Glazing Area (Glass) m2	34.2	36.9	21.0	12.2	20.9
Effective Due South Glazing m2	30.4	21.9	11.7	5.4	2.5
Glass/Main Facade inc Roof	49.5%	45.9%	24.2%	10.3%	6.3%

Mid Terrace House Type Metrics

Prototype:	Control Mid Terrace	NORD MID Terrace
		
Areas		
Floor Area m2	107.0	110.8
Volume m3	508.0	426.6
Volume (Ventilation) m3	268	277
Area/ Volume Ratio (Gross) m2/m3	0.56	0.75
Exposed Surface Area m2	284	319
Glazing Area (Glass) m2	34.2	36.6
Effective Due South Glazing m2	30.4	8.2
Glass/Main Facade inc Roof	49.5%	23.4%

End Terrace House Type Metrics



Prototype:	Control Semi Detached	NORD End Terrace
		
Areas		
Floor Area m2	107.0	110.8
Volume m3	508.0	439.6
Volume (Ventilation) m3	268	277
Area/ Volume Ratio (Gross) m2/m3	0.64	0.86
Exposed Surface Area m2	328	378
Glazing Area (Glass) m2	34.2	36.0
Effective Due South Glazing m2	30.4	5.3
Glass/Main Facade inc Roof	49.5%	10.9%

Figure 155- Building Metrics

Results

[Figure 156] Specific Space Heat Demand Exemplar Comparison

[Figure 157] Heat Load Exemplar Comparison

[Figure 158] Detached SSHD and Window Heat Balance Exemplar Comparison

[Figure 159] Detached SSHD and Exposed Surface Area Exemplar Comparison

For clarity the results of this initial study have been categorised into housing typologies. The typologies are; detached, semi-detached/end terrace and mid-terrace. The results illustrate the variation of the SSHD due to the building form. The main contributing factors to the variation in SSHD are:

- Exposed surface area of the designs – heat losses through fabric
- Energy balance of the windows

The use of the weighted u-values in the study is intended to set a base line where the control prototypes achieve a SSHD of 15 kWh/(m²a), the weighted specification of the wall and roof compensate for different building typologies and climates. The weighted u-values across the different climatic regions compensate for increased heat losses through lower temperatures and reduced heat gains. The weighted u-values in the West of Scotland detached prototype are 0.157 W/(m²K) as the climate is relatively mild with generous solar gains. As there is a significant variation between the West of Scotland and Orkney in terms of climate and SSHD (8.6 kWh/(m²a)) the weighted u-values in Orkney are significantly lower at 0.091 W/(m²K). The results of the comparative study appear misleading with the more onerous Orkney climate generally producing lower SSHD and HL requirements across the exemplary, less efficient building forms. In all of the exemplar designs

analysed the West of Scotland climate has slightly higher gains than Orkney but also higher heat losses mainly through the walls and roof due to the lower thermal specification (weighted u-value). Therefore the better Orkney results reflect the reduced heat losses due to the higher performance of the walls and roof when compared to the West of Scotland.

The variation in SSHD and heat load across the prototypes is significant. The SSHD has implications on the overall heating costs for the designs. The variations in heat load illustrate the likely thermal stability of the design, with higher heat load requirements needing more powerful heating systems to retain thermal comfort. Both graphs are organised with the lowest SSHD to the left in each typology. There is a substantial increase in SSHD between the 107m² control prototype and the worst performing Clousta House with a SSHD of 42 kWh/(m²a) in the West of Scotland. Although, in terms of heat load graph the Clousta house performs close to the Passivhaus requirement of 10.3 W/m². One of the best performing houses for both SSHD and heat load is the Dualchas Borerraig house which is close to the performance of the control house with a SSHD of 18.7 kWh/(m²a) in Orkney and a heat load of 10.3 W/m². The compact form and small openings of the Rural Design house excels in heat load performance with 8.6 W/m². The NORD house types all perform badly in comparison to the prototype in terms of both heat load and SSHD performance.

A focus on the detached house SSHD performance compared to the window heat balance which illustrates the correlation between the trend towards low window heat balance and SSHD in all cases apart from the Borerraig house. This could be attributed to the efficient window sizing and placement compensating for the inefficient plan layout and high exposed surface area. The exposed surface area graph (Figure 159) does not demonstrate the direct relationship with the SSHD but it is a major factor. The window heat balance is a more effect comparative metric (Figure 158) to determine how well a building will perform in terms of SSHD. This is because it demonstrates how effectively windows are performing in terms of heat gains vs. losses, therefore and how effectively the house is receiving and retaining solar gains through glazing. The window heat balance across the designs ranges from 3510 kWh (Borerraig) and 99 kWh (Clousta). This almost correlates with the SSHD but due to the Borerraig's heat lost through other areas of the fabric it's SSHD is higher than the prototype and the R2 house (in Orkney).

The higher thermal performance of the building envelope (lower u-value) in Orkney allows the designs to show a comparatively lower increase in SSHD due to reduced heat losses. Therefore the increased thermal envelope specification will allow for the climate to have a smaller effect on the heat loss. This appears to have beneficial effects for some of the house types that demonstrate high SSHD but low heat load requirements such as the Clousta and Outer Hebrides Kit house designs. These results indicate the large variation of SSHD caused by different design approaches. The study also demonstrates the suitability of meeting the Passivhaus heat load certification criteria rather than attempting to reduce the SSHD with traditionally styled houses such as the Clousta and Outer Hebrides Kit house designs. These traditionally styled houses have smaller windows which reduces construction costs and heat losses. Due to the reduced heat losses they are less reliant on solar heat gains, therefore have greater flexibility for changes to orientation. This heat load certification method using smaller windows are used in BERE's low cost Lime House Passivhaus (BERE Architects 2012b).

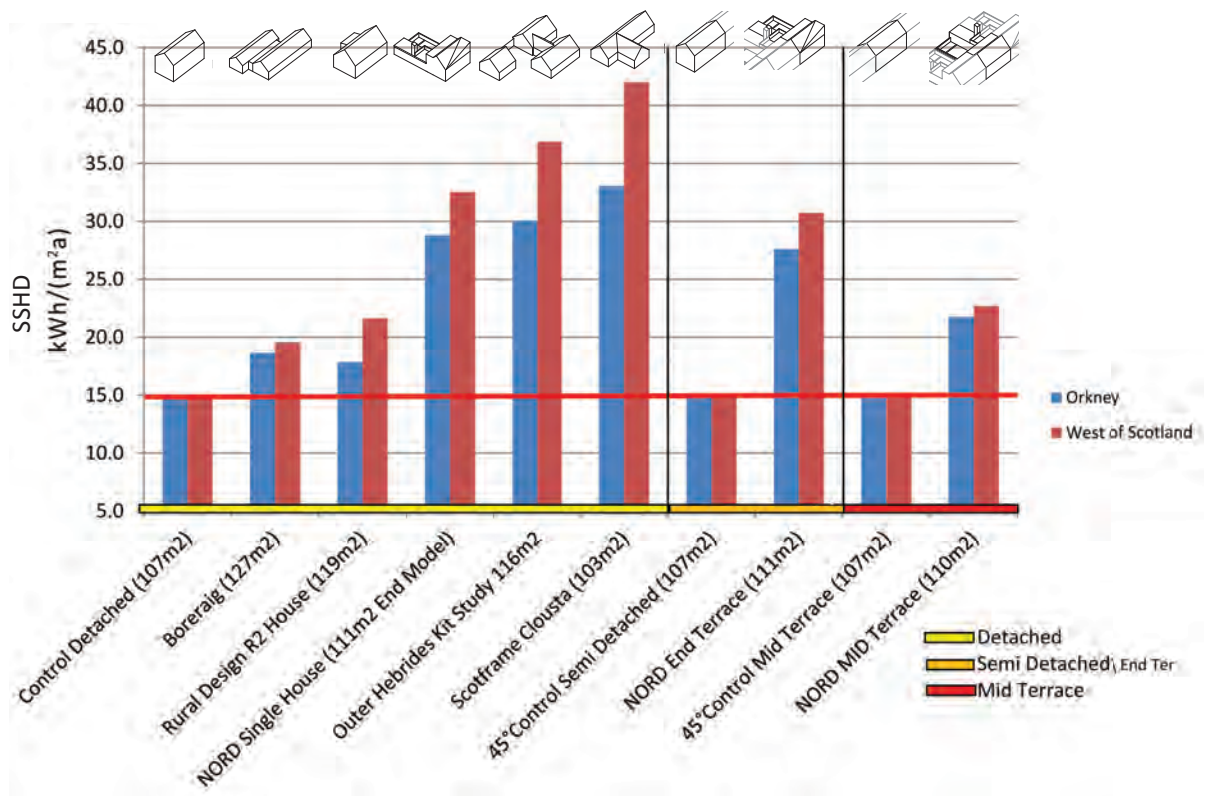


Figure 156- Specific Space Heat Demand Comparison

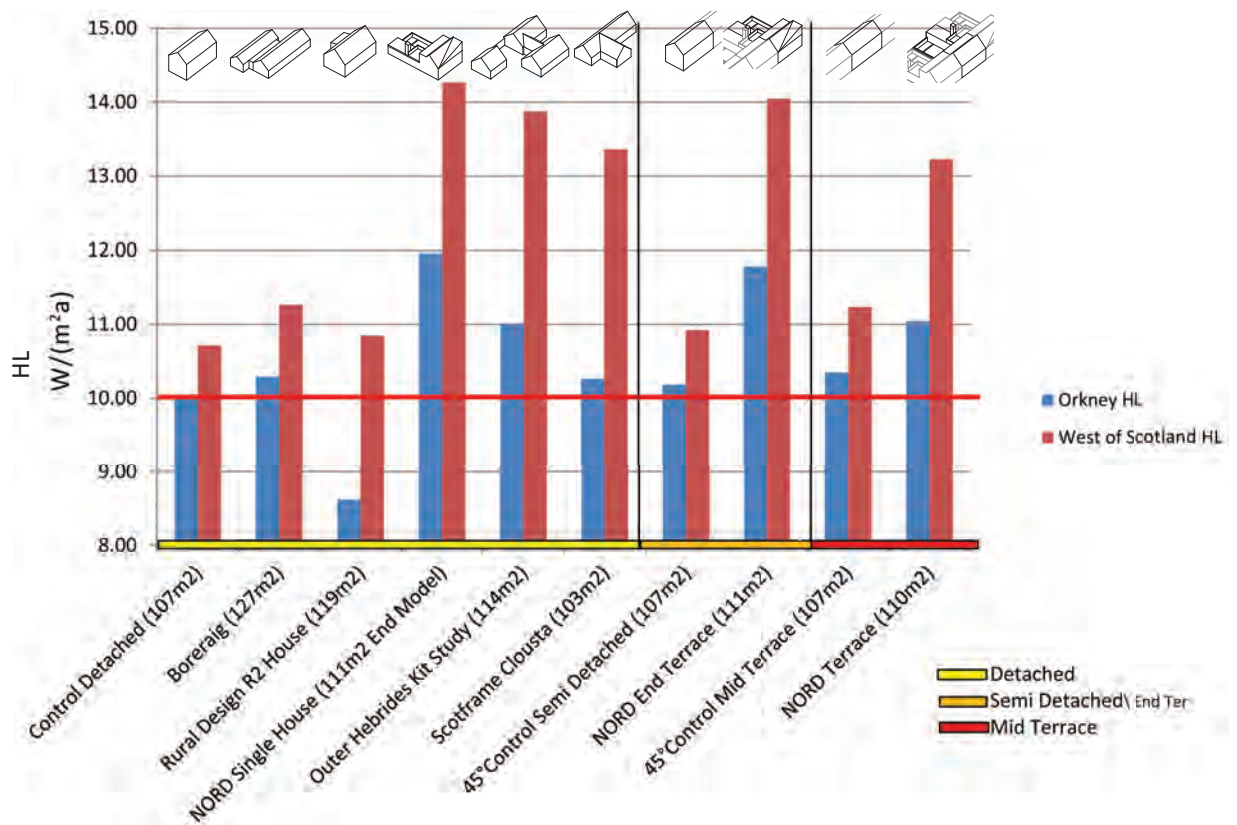


Figure 157- Heat Load Comparison

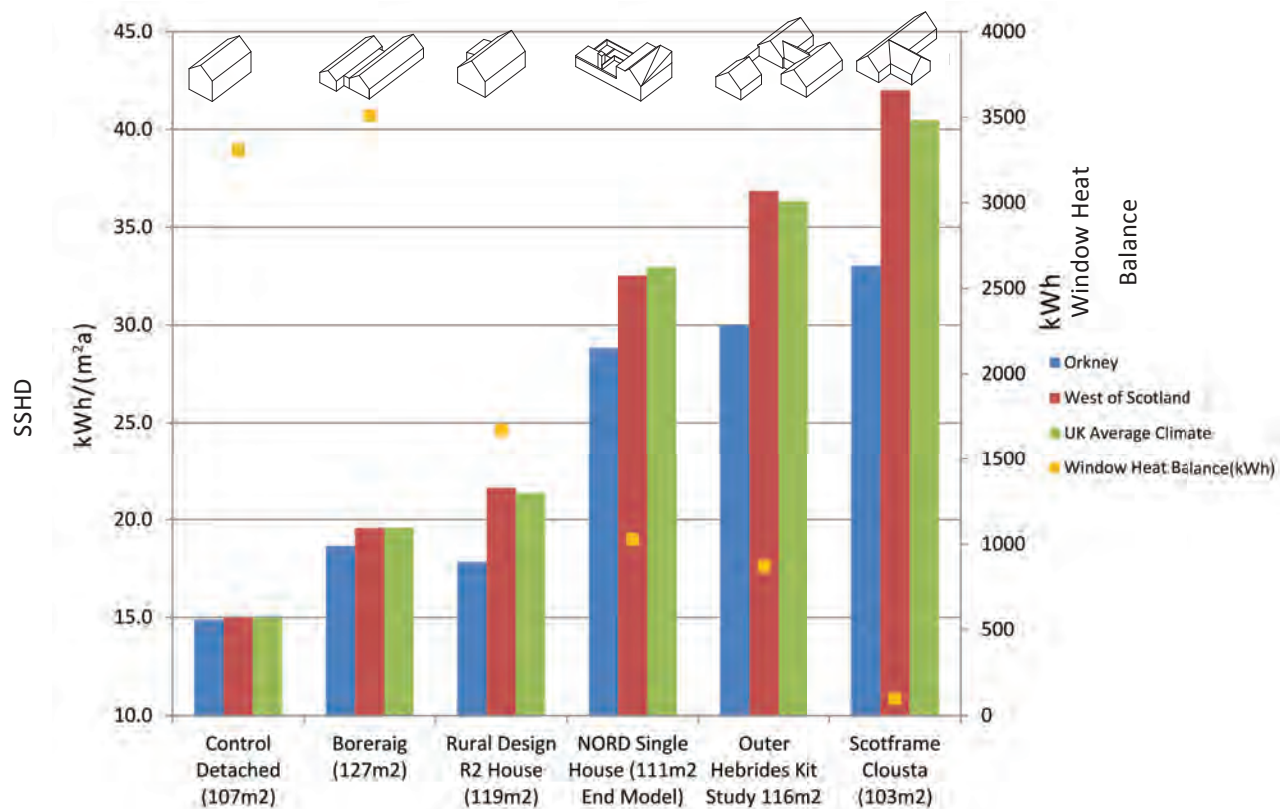


Figure 158- Detached SSHD and Window Heat Balance Comparison

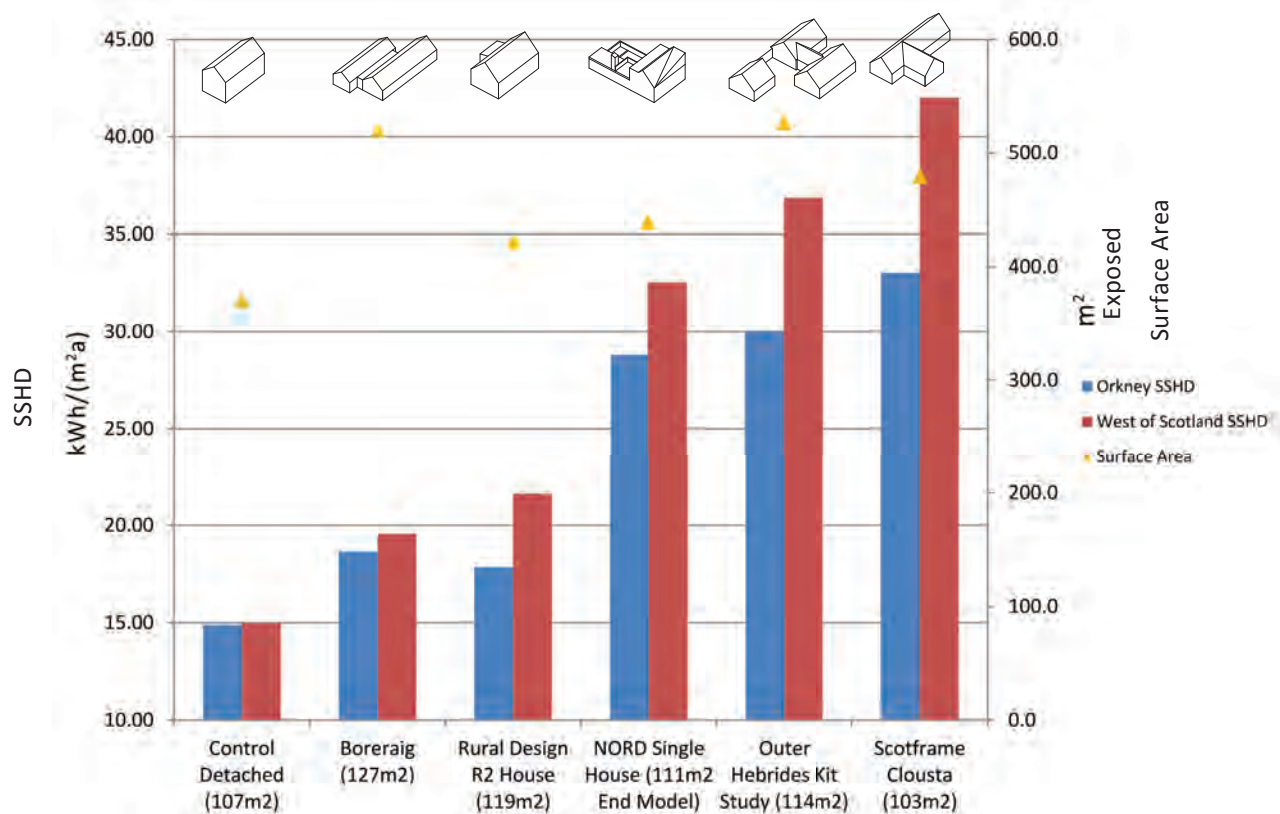


Figure 159-Detached SSHD and Exposed Surface Area Comparison

7.4. Study 2: Passive Solar Optimisation of Exemplar House Designs

The SSHD and heat load (HL) of the exemplar house designs are optimised through alterations of the orientation and window sizes rather than planning or formal variations in the extremes of the Scottish climate in this study. The aim is to allow for an optimisation of building performance without significantly compromising the design integrity and the associated relationship to the design's original context. In practice the reduction of SSHD and carbon emissions would generally be achieved by decreasing the u-value (increasing thermal performance) of the building elements or adding renewable technology. The impact and viability of increasing the thermal performance of the building elements is an approach discussed in some of the optimisation studies. The design alterations in the following study are not exhaustive, as there are many different variations possible. The alterations to the designs will illustrate the reduction on SSHD and HL through quantitative improvements to the form and orientation. It has been demonstrated that these variables have significant effect both the SSHD and HL in sections 6.5.2 (2B) and 6.5.5 (2E). Altering other variables such as the roof form or plan type was deemed too intrusive to the design of the exemplars. In addition, alteration of the roof form has a relatively small effect on HL, demonstrated in 6.5.3, Study 2C.

7.4.1. Study Variables

Window size and positioning is altered with comments regarding the suitability of the changes when considering the impact these have on spatial quality and operation of the plan. The optimisation process firstly establishes the most efficient orientation for the unaltered design. The design is then assessed in terms of any windows that have low energy balance. If possible low performing windows are resized or relocated to either lower SSHD or HL. Windows which will increase solar gains are altered to lower SSHD through passive solar gain principles.

- Climate Data
- Orientation
- Window Size
- Window Location

House Designs

Exemplars

- Dualchas, Boreraig
- Rural Design. R2 House
- Scotframe, Clousta
- Proctor and Matthews Architects ,Outer Hebrides Kit Study Prototype
- NORD, Stone House Detached House (111m² End Terrace Model)
- NORD, Stone House (111m² End Terrace)
- NORD, Stone House (107m² Mid Terrace)

Illustration of Variations

Three dimensional images of the optimised designs are over marked with either blue or red. Blue denotes increased glazing area and red denotes removal or reduction of glazing area.

7.4.2. Dualchas, Boreraig

[Figure 160]

Orkney Results

Inputs Boreraig

Areas

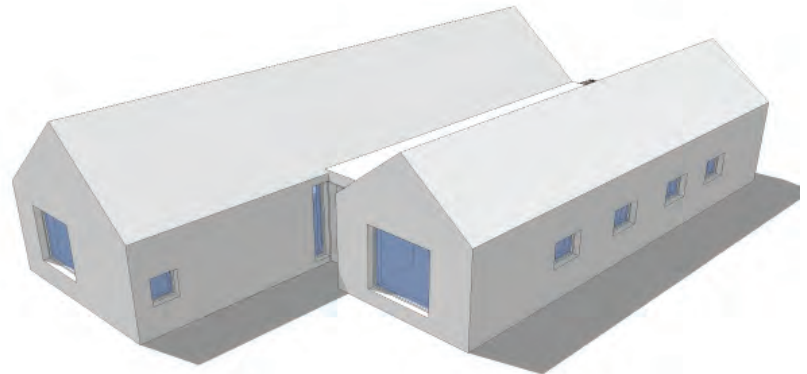
Floor	127.2693	
North Wall	45.80907	8
South Wall	47.80268	8
East Wall	33.98753	8
West Wall	33.98753	8
Floor Slab	157.8162	60.7
Roof	198.783	
party Wall	Roof WEST	
party Wall	Roof EAST	

Windows

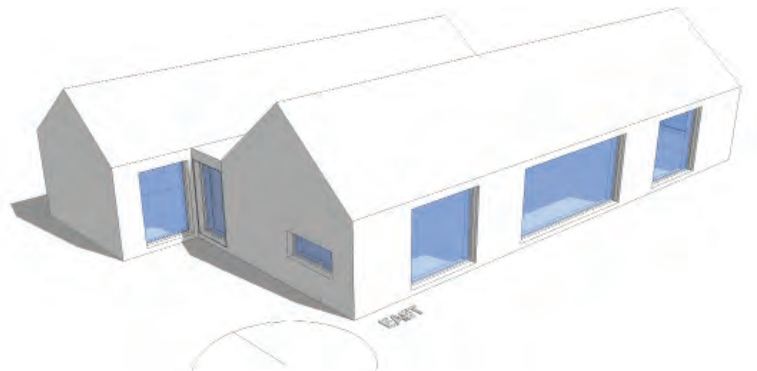
	Width	Height	No	Dev Nrth
North Wind	1.05	0.7	4	1
2	0.5	2.1	1	1
3	0.7	0.7	1	1
4	0	0	0	1
East Wind	1.65	1.5	1	3
2	1.95	2.1	1	3
3	0	0	0	3
4	0	0	0	3
South Wind	2.3	2.1	2	2
2	4.4	2.1	1	2
3	1.45	2.1	1	2
4	0	0	0	2
West Wind	1.7	0.7	1	4
2	1.3	2.1	1	4
3	0	0	0	4
4	0	0	0	4
Horizontal	0	0	0	6
	0	0	0	0
	0	0	0	0
	0	0	0	0
Door	0.925	2.2	1	

Volumes

Enclosed (	510	
Ventilation	318.1732	318.1732
Airtightness	0.6	



North East Elevation View



South West Elevation View

Figure 160- Boreraig Inputs & Model

SSHD: 18.7 kWh/(m²a)

HL: 10.29 W/m²

West of Scotland (WOS) Results

SSHD: 19.6kWh/(m²a)

HL: 11.27 W/m²

Performance Analysis

The Boreraig house was the best performing house of the exemplars studied. This is due to the effectiveness of the south facing windows and minimal heat losses through glazing to the north. The proportion of exposed surface area is significantly higher (520m²) than the 107m² prototype (371m²) due to the larger floor area and single storey complex plan. This translates into a 23% (Orkney) and a 25% (WOS) increase of SSHD over the 107m² prototype. The higher exposed surface area is reflected by the heat losses through the

ground and roof at 14 kWh/(m²a) double that of the 107m² design. However the heat loss from the walls of the control type comes close to balancing out the roof and ground losses. Due to the overall increased heat losses the Dualchas design makes slightly better use of the available gains with a solar utilisation factor of 71% compared to the control's 65%.

Boreraig Fabric Improvement Study

Fabric Performance Improvement Study

If the u-values of the walls and roof were to be increased to allow the house to meet Passivhaus requirement it would result in the following values:

Fabric alteration to achieve PH SSHD

- Orkney 0.067 W/(m²K) (from 0.091 W/(m²K))
- WOS 0.124 W/(m²K) (from 0.157 W/(m²K))

Fabric alteration to achieve PH Heat Load

- Orkney 0.084 W/(m²K) (from 0.091 W/(m²K))
- WOS 0.127 W/(m²K) (from 0.157 W/(m²K))

Therefore, to meet the Passivhaus criteria in the WOS there is little difference in the increase of u-value between the SSHD and HL requirements. In Orkney meeting the HL criteria involves much less of a fabric improvement, suggesting that this type would respond more favourably to the HL certification of PH.

SSHD Optimisation for Orkney

This altered version of the house type performs very well in the climate. The orientation is well suited to make good use of the solar gain available. Analysis of the plan reveals that north facing openings can be reduced without having damaging effects on the plans function.

Glazing Reduction

- Bathroom from 1.05x0.7m to 0.7x0.7m
- Removal of North Facing Living room window
- Narrowing of 3x Remaining Windows to 0.95m

These minor reductions in the area of north facing glazing drops the SSHD to 17.9 kWh/(m²a).

Glazing Increase

- South glazing -45% to 50%
- West Reduction by 1 m²
- East Reduction by 2.66m²

These alterations do not have a significant effect on the planning and reduce SSHD to 17.098kWh/(m²a). The alterations to elevations are noticeable, therefore possibly altering the architects design ideas. Due to a small range of window size reductions to the North, West and East elevations and increasing the south the SSHD can be reduced from 18.7 kWh/(m²a) to 17.1 kWh/(m²a) a 9% saving. Meeting the PH criteria for SSHD would

require a small increase in thermal envelope specification or alterations to the house planning. However the Passivhaus heat load requirement of 10 W/m² is met with the alterations in the Orkney climate. The already high performance of the design in the West of Scotland climate was increased further by the range alterations above showing a 7% reduction in SSHD and an improved heat load of 10.881 W/m². The further increase in south facing glazing would be more beneficial in the WOS climate but would have a detrimental effect on the plan.

Boreraig Summary

Inputs Dualchas ALTERED SSHD Orkney

Areas

Floor	127.3	
North Wall	45.8	8
South Wall	47.8	8
East Wall	34.0	8
West Wall	34.0	8
Floor Slab	157.8	Perimeter
Roof	198.8	60.7
party Wall Roof WEST	0.0	
party Wall Roof EAST	0.0	

Windows

	Width	Height	No	Dev Nrth
North Windows	0.95	0.7	3	1
2	0.5	2.1	0	1
3	0.7	0.7	0	1
4	0.7	0.7	1	1
East Windows	1.4	1.4	1	3
2	1.95	1	1	3
3	0	0	0	3
4	0	0	0	3
South Windows	2.8	2.1	2	2
2	4.4	2.1	1	2
3	1.45	2.1	1	2
4	0	0	0	2
West Windows	1.2	0.7	1	4
2	1	2.1	1	4
3	0	0	0	4
4	0	0	0	4
Horizontal Windows	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
Door	0.925	2.2	1	

Volumes

Enclosed (Gross Volume)	510.0	
Ventilation Volume	318.1732	318.1732
Airtightness Rate	0.6	

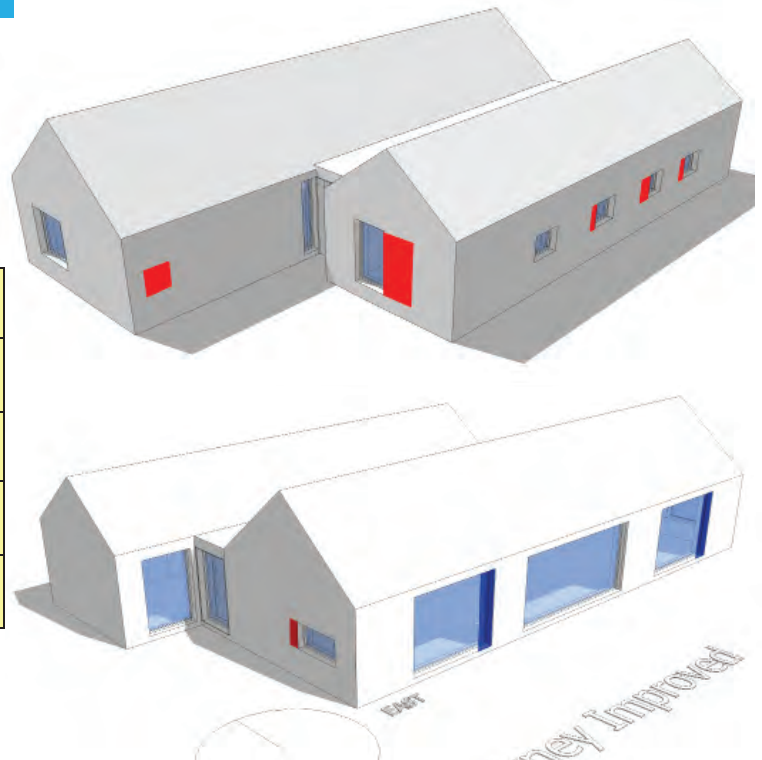


Figure 161- Boreraig Optimised Model

[Figure 161]

Orkney Optimised Results

SSHD: 17.1kWh/(m²a)

HL: 9.9W/m²

West of Scotland (WOS) Optimised Results

SSHD: 18.2kWh/(m²a)

HL: 10.9W/m²

This house type performed the best in terms of SSHD with no alterations due to a relatively good balance between well orientated windows and heat losses though the inefficient volumetric form and window with little contribution to solar gains. Through optimisations the SSHD could be reduced slightly further. This design shows a well-considered approach to traditional formal references and elevation design to take advantage of solar gains.

7.4.3. Rural Design. R2 House

[Figure 162]

Inputs Rural Design R2 House

Areas

Floor	118.694	
North Wall	44.33211	8
South Wall	48.25797	8
East Wall	47.19243	8
West Wall	47.19243	8
Floor Slab	98	43.2
Roof	134.9016	
party Wall Roof WEST	0	
party Wall Roof EAST	0	

Windows

	Width	Height	No	Dev Nrth
North Windows	0.7	0.85	2	1
2	1.1	1.2	1	1
3	0	0	0	1
4	0	0	0	1
East Windows 1	1.3	1.45	1	3
2	0	0	0	3
3	0	0	0	3
4	0	0	0	3
South Windows	1.3	2.26	2	2
2	0	0	0	2
3	0	0	0	2
4	0	0	0	2
West Windows 1	1.3	1.4	1	4
2	0	0	0	4
3	0	0	0	4
4	0	0	0	4
Horizontal Windows	1.05	1.05	2	6
	0.95	0.95	1	6
	1.1	1.75	2	6
	1.55	1.25	1	6
Door	1.1	2.3	1	

Volumes

Enclosed (Gross Volume)	522.938	East x Leng
Ventilation Volume	296.735	Length
Airtightness Rate	0.6	

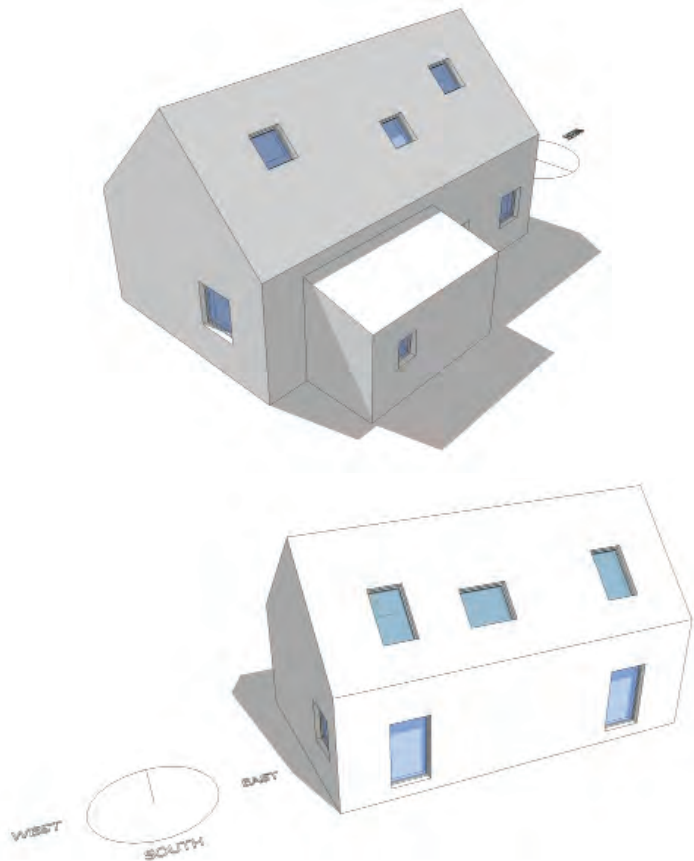


Figure 162- R2 Inputs & Model

Orkney Results

SSHD: 17.8 kWh/(m²a)

HL: 8.62 W/m²

West of Scotland (WOS) Results

SSHD: 21.6 kWh/(m²a)

HL: 10.85 W/m²

Performance Analysis

The rural design R2 house was the second best performing house excluding the control prototype and Dualchas Borerai house. Unlike the Dualchas Borerai house, the Rural Design R2 house is relatively compact with a small exposed surface area. However, the design only has 15% glazing to its south elevation (or 24% including the roof). This greatly reduces the amount of solar gain available (29 kWh/(m²a)) in comparison to the control prototype (58 kWh/(m²a)) and the Dualchas design (51 kWh/(m²a)). This figure is reflected in the overall energy balance of the windows with an overall balance of 1671 kWh energy gain over the

year compared with the control's 3308kWh gain. The one and a half storey section minimises the heat lost through the wall, the additional entrance and utility area create a similar heat loss figure of 13.6 kWh/(m²a) compared with the prototypes 15.1 kWh/(m²a)) in Orkney. The compact form and small windows allows the buildings heat load to come in under the Passivhaus requirement of 10 (W/m²) at 8.6 in Orkney (W/m²) and slightly higher in WOS, 10.8 (W/m²).

R-House Fabric Orientation Study

The orientation of the design is already optimal, therefore altering the orientation will only increase both the heating load and SSHD.

West of Scotland - Rural Design

Heat Load Optimisation

Inputs Rural Design R2 Improved HL					
Areas					
Floor	118.694				
North Wall	44.33211	8			
South Wall	48.25797	8			
East Wall	47.19243	8			
West Wall	47.19243	8	Perimeter		
Floor Slab	96			43.2	
Roof	134.9016				
party Wall Roof WEST	0				
party Wall Roof EAST	0				
Windows					
	Width	Height	No	Dev	Nrth
North Windows	0.7	0.85	2		1
2	0.7	0.7	1		1
3	0	0	0		1
4	0	0	0		1
East Windows 1	1.3	1.45	1		3
2	0	0	0		3
3	0	0	0		3
4	0	0	0		3
South Windows	1.3	2.26	2		2
2	0	0	0		2
3	0	0	0		2
4	0	0	0		2
West Windows 1	1.3	1.4	1		4
2	0	0	0		4
3	0	0	0		4
4	0	0	0		4
Horizontal Windows	1.05	1.05	0		6
	0.95	0.95	1		6
	1.1	1.75	2		6
	1.55	1.25	1		6
Door	1.1	2.3	1		
Volumes					
Enclosed (Gross Volume)	522.938				
Ventilation Volume	296.735	296.735			
Airtightness Rate	0.6				

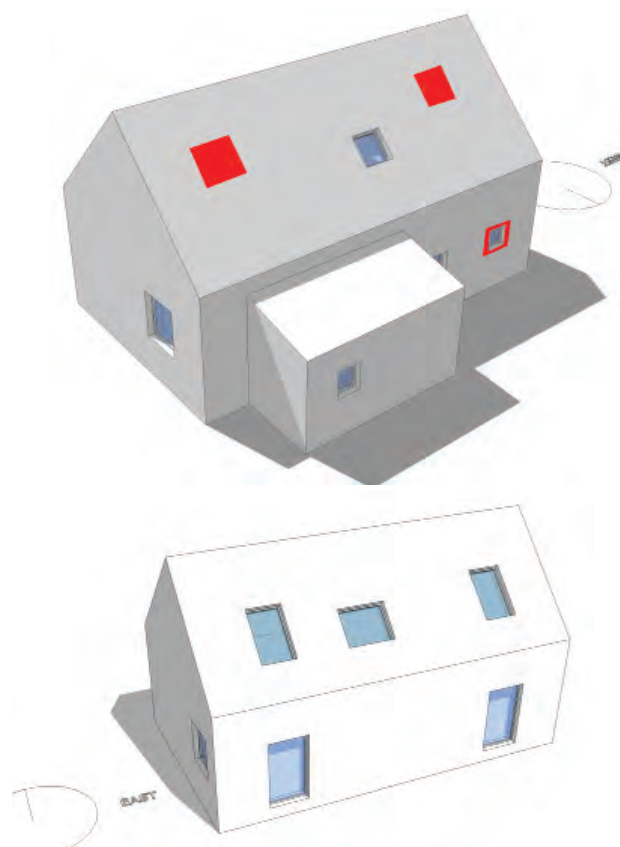


Figure 163- R2 Heat Load Optimisation

[Figure 163]

Due to the design already meeting the heat load requirement in Orkney, this section of the study will focus on the WOS climate data. Typically to lower heat load the reduction of heat losses is recommended. Therefore this method to lower the heat load of the building is difficult due to the small windows and compact form. The two possible improvements which are not detrimental to the plan is to remove the 2 north facing roof lights and the reduction of north facing kitchen windows (from 1.1x1.2m to 0.07x0.07m). Making the south windows smaller adversely effects both the SSHD and Heat Load. These alterations only give a small

reduction 10.546 W/m² (from 10.850 W/m²).

SSHD Optimisation West of Scotland

[Figure 164]

Rural Design R2 Improved (Large Sth, Cut Nrt) W

	(8 Norm 18 party)	
Floor	118.694	
North Wall	44.33211	8
South Wall	48.25797	8
East Wall	47.19243	8
West Wall	47.19243	8 Perimeter
Floor Slab	98	43.2
Roof	134.9016	
party Wall Roof WEST	0	
party Wall Roof EAST	0	

	Width	Height	No	Dev Nrt
North Windows	2	0.7	0.85	2
	3	0.7	0.7	0
	4	0	0	1
	4	0	0	1
East Windows 1	2	1.3	1.45	1
	3	0	0	3
	4	0	0	3
	4	0	0	3
South Windows	2	3.7	2.26	2
	3	0	0	2
	4	0	0	2
	4	0	0	2
West Windows 1	2	1.3	1.4	1
	3	0	0	4
	4	0	0	4
	4	0	0	4
Horizontal Windows	2	1.05	1.05	0
	3	0.95	0.95	1
	4	1.1	1.75	2
	4	1.55	1.25	1
Door	1.1	2.3	1	

Enclosed (Gross Volume)	522.938
Ventilation Volume	296.735
Airtightness Rate	0.6

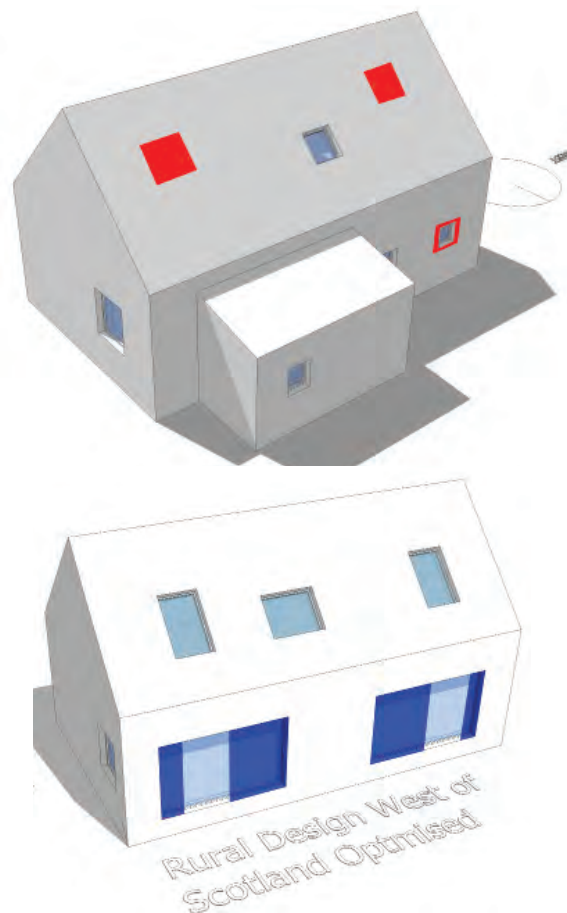


Figure 164- R2 SSHD West of Scotland Optimisation

Substantially increasing the South Window (5.9m² to 16.7m²) and removal of the north facing roof lights results in a large decrease in SSHD to 14.891 kWh/(m²a) and a HL of 10.019 W/m². It is worth noting that despite the large area of glazing this alteration does not cause over-heating warnings in the PHPP results sheet based on 50 % effective solar shading to the south. Interestingly the heat load is reduced despite the larger glazing area. This is due to the more efficient window energy balance.

SSHD Optimisation Orkney

[Figure 165]

Following the same principles in Orkney a smaller increase in south facing glazing (12.7m²) and the reintroduction of a north facing roof light will produce a 15.094 kWh/(m²a) SSHD and 8.788 W/m² heat load requirement. Using the optimised Orkney prototype u-value could be increased from 0.091W/(m²K) to 0.118 W/(m²K), reducing the cost of the insulation and kit construction.

Inputs Rural Design R2 Relaxed ORKNEY

Areas			
Floor	118.694		
North Wall	44.33211	8	
South Wall	48.25797	8	
East Wall	47.19243	8	
West Wall	47.19243	8	Perimeter
Floor Slab	98		43.2
Roof	134.9016		
party Wall Roof WEST	0		
party Wall Roof EAST	0		

Windows		Width	Height	No	Dev Nrth
North Windows		0.7	0.85	2	1
	2	1.1	1.2	1	1
	3	0	0	0	1
	4	0	0	0	1
East Windows	1	2	2.26	1	3
	2	0	0	0	3
	3	0	0	0	3
	4	0	0	0	3
South Windows		2.8	2.26	2	2
	2	0	0	0	2
	3	0	0	0	2
	4	0	0	0	2
West Windows	1	1.3	1.4	1	4
	2	0	0	0	4
	3	0	0	0	4
	4	0	0	0	4
Horizontal Windows		1.2	1.2	2	6
		0.95	0.95	1	6
		1.2	1.75	2	6
		1.55	1.25	1	6
Door		1.1	2.3	1	

Volumes			
Enclosed (Gross Volume)	522.938		
Ventilation Volume	296.735	296.735	
Airtightness Rate	0.6		

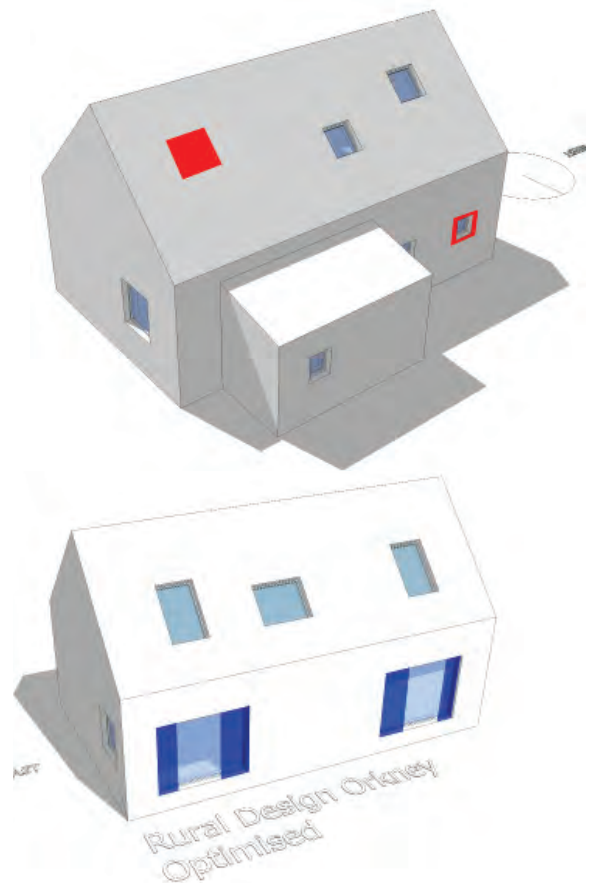


Figure 165- R2 SSHD Orkney Optimisation

R-House Summary

Orkney Optimised Results

SSHD: 15.1 kWh/(m²a)

HL: 8.7 W/m²

West of Scotland (WOS) Optimised Results

SSHD: 14.9 kWh/(m²a)

HL: 10 W/m²

The R-House demonstrates the viability of simple compact forms, south orientation, reduction of north glazing and optimisation of south glazing which accords with the principles used in the simple uncomplicated architecture of traditional rural building forms. The traditionally styled house type performs well due to the two storey compact form. The zoning of accommodation within the 40 degree symmetrical pitch roof layout decreases the exposed surface area in comparison with a standard two storey mode and the consequent increase in the exposed wall surface area as a result of the second storey. The fine tuning of the glazing, partially by increasing the glazing areas, has a beneficial effect. The traditional form incorporating large, appropriately orientated glazing openings, which are properly orientated, creates an extremely viable ultra-low energy house that outperforms the initial best practice form.

7.4.4. Scotframe, Clousta

[Figure 166]

Orkney Results

SSHD: 33.0 kWh/(m²a)

Inputs Scotframe Clousta 107m²

Areas

Floor	102.937	
North Wall	44.04732	8
South Wall	52.02158	8
East Wall	35.36187	8
West Wall	35.32759	8
Floor Slab	128.7353	57.24
Roof	182.2882	
party Wall Roof WEST		
party Wall Roof EAST		

Windows

		Width	Height	No	Dev Nrth
North Windows	1	0.75	1.05	2	1
	2	0.95	1.05	1	1
	3	0.9	1.05	2	1
	4	0	0	0	1
East Windows	1	0.75	1.05	2	3
	2	0	0	0	3
	3	0	0	0	3
	4	0	0	0	3
South Windows	1	0.9	1.05	4	2
	2	0.75	1.05	2	2
	3	0.7	1.05	1	2
	4	0	0	0	2
West Windows	1	0.75	1.05	1	4
	2	0	0	0	4
	3	0	0	0	4
	4	0	0	0	4
Horizontal Windows		0	0	0	0
		0	0	0	0
		0	0	0	0
		0	0	0	0
Door		0.9	2.1	1	

Volumes

Enclosed (Gross Volume)	539.177	386.1312	122.4366	30.60916
Ventilation Volume	257.3425	257.3425		
Airtightness Rate	0.6			

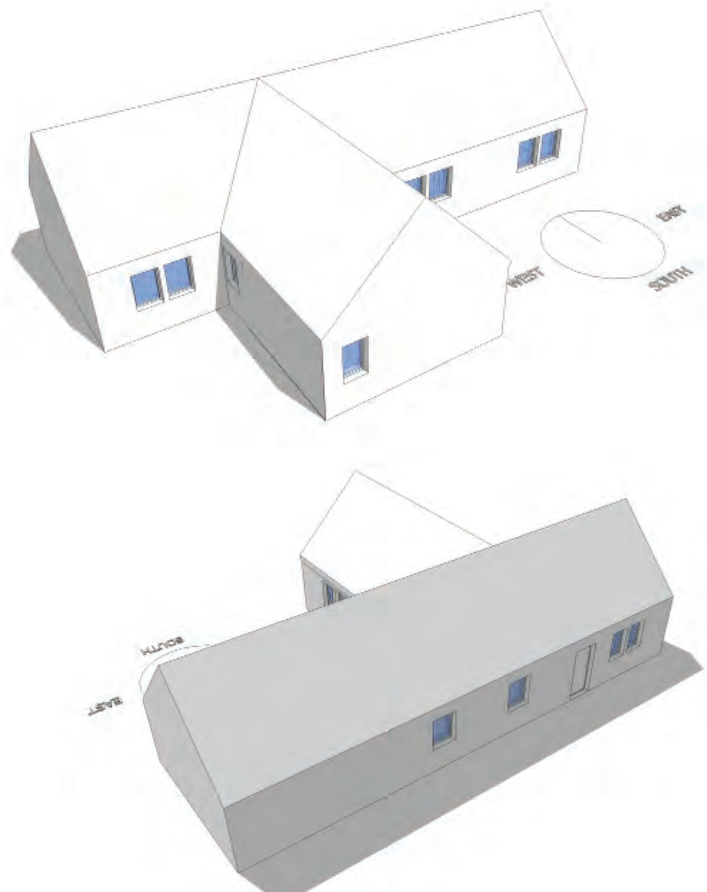


Figure 166- Scotframe Clousta Inputs & Model

HL: 10.26 W/m²

West of Scotland (WOS) Results

SSHD: 42.0 kWh/(m²a)

HL: 13.36 W/m²

Performance Analysis

The Scotframe house has a significantly higher exposed surface area (480m²) compared with the PH prototype (371m²) despite a 4m² smaller floor area. This is due to the complex aggregated plan form with all the accommodation organized on one floor and the subsequent increase in roof area needed. This single story layout is similar to the Dualchas type however, in the Clousta design the solar gain through the openings do not compensate for the extra heat losses through the exposed surface area. Scotframe's Clousta house was the worst performing design in the study in terms of SSHD. This is due to the low heat gains through

openings which gives a low overall window heat balance. The window heat balance is the lowest in the study with the windows contributing only 99 kWh over the course of a year in comparison to the Borerraig at 3510 kWh. This also generates a low contribution through solar gain of 11.9 kWh/(m²a) in comparison to in the control prototype at 37.8 kWh/(m²a). Conversely to the SSHD figure the design has a comparable heat load to the control prototype. The low heat load figure is due to reduced heat losses through the small area of openings and high level of thermal insulation in the roof and walls. Therefore the size of a heating system will be extremely small. The heat load is almost low enough to meet the Passivhaus requirement in the Orkney climate and would require larger additional improvements to the fabric performance in the other climates if it were to meet the PH benchmark

Orientation alteration

Due to the type not having a site the orientation of the current design allows for the most efficient use of the design's original fabric.

Clousta Fabric Improvement Study SSHD

Due to the high SSHD to achieve the required 15 kWh/(m²a) SSHD through an increase of the u-values of the walls and roof it would result in the following values:

- Orkney- 0.032 W/(m²K) (from 0.091 W/(m²K))
- West of Scotland- 0.056 W/(m²K) (from 0.157 W/(m²K))

To put these figures into perspective, the extra insulation to meet the Passivhaus required 15 kWh/(m²a) the West of Scotland would increase the thickness typical Passivhaus wall build (0.157W/(m²K))a from 273mm to 633mm. To improve the performance of the wall and roof to match this specification would be unrealistic.

Clousta Fabric Performance Improvement Study HL

The HL figure of 10.3 W/m² in Orkney is very close to the PH benchmark, requiring a small fabric performance increase to achieve the Passivhaus requirement of 10 W/m² in Orkney and a higher increase in WOS. The low heat load results in a far smaller fabric performance increase to meet the 10w/m² heat load target than meeting the SSHD requirement through the same means.

- Orkney- 0.086 W/m². (from 0.091 W/(m²K))
- West of Scotland- 0.1 W/m² (from 0.157 W/m²)

South Window Increase SSHD Improvement

West of Scotland

Increase of the south facing gable and increase in the size of the four smaller windows produce a significant reduction on SSHD. This represents an increase of the south elevation from 11.7% to 35.75% glazed.

- South Glazing increase- 0.7x 1.105m to 4.5x2.5m.
- 4x Windows increase- 0.9x1.15m to 1.2x1.105m

This lowers the SSHD to 26.712 kWh/(m²a) from 42.0 kWh/(m²a) and also leads to a small decrease in HL to 12.829 W/m². This figure is major improvement however, it is still higher than the SSHD of the original Dualchas design at around 17 kWh/(m²a).

Orkney

The same alterations in the Orkney climate take the SSHD from 33 kWh/(m²a) to 22.887 kWh/(m²a). Similarly to the West of Scotland, in the Orkney climate the type is heavily reliant on solar gains to balance the heat lost from the inefficient envelope.

Clousta Summary

[Figure 167]

Inputs Scotframe Clousta SSDH					
Areas					
Floor	102.937				
North Wall	44.04732	8			
South Wall	52.02158	8			
East Wall	35.36187	8			
West Wall	35.32759	8	Perimeter		
Floor Slab	128.7353			57.24	
Roof	182.2882				
party Wall Roof WEST					
party Wall Roof EAST					
Windows					
	Width	Height	No	Dev	Nrth
North Windows	1 0.75	1.05	2	1	
	2 0.95	1.05	1	1	
	3 0.9	1.05	2	1	
	4 0	0	0	1	
East Windows	1 0.75	1.05	2	3	
	2 0	0	0	3	
	3 0	0	0	3	
	4 0	0	0	3	
South Windows	1 1.3	1.05	4	2	
	2 0.9	1.05	2	2	
	3 4.5	2.5	1	2	
	4 0	0	0	2	
West Windows	1 0.75	1.05	1	4	
	2 0	0	0	4	
	3 0	0	0	4	
	4 0	0	0	4	
Horizontal Windows	0 0	0	0	0	
	0 0	0	0	0	
	0 0	0	0	0	
	0 0	0	0	0	
Door	0.9	2.1	1		
Volumes					
Enclosed (Gross Volum	0				
Ventilation Volume	257.3425	257.3425			
Airtightness Rate	0.6				

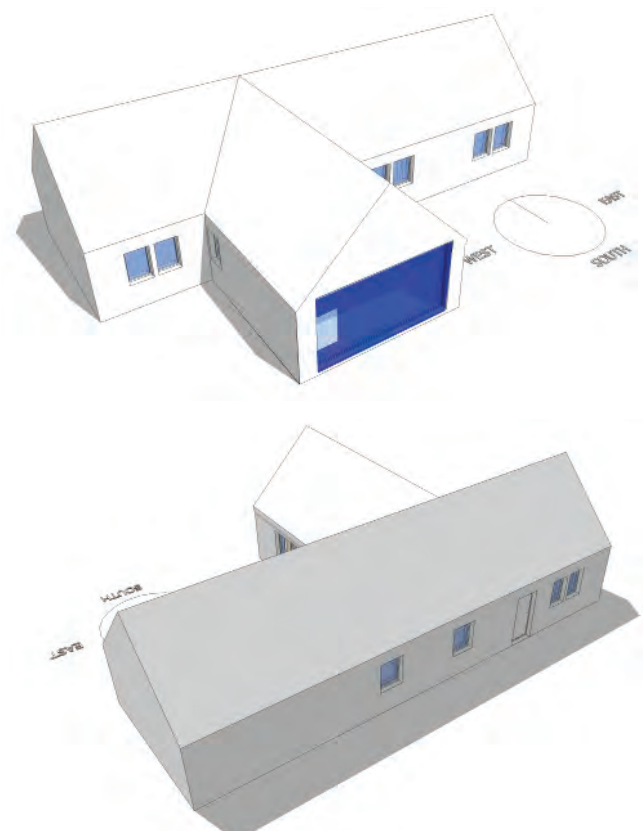


Figure 167- Scotframe Clousta Optimised Model

Orkney Optimised Results

SSHD: 22.9 kWh/(m²a)

HL: 10.3 W/m²

West of Scotland Optimised (WOS) Results

SSHD: 26.7 kWh/(m²a)

HL: 12.8 W/m²

The SSHD of this type was significantly higher than the prototype and all of the designs in the study. The combination of a relatively large surface area and small windows, partly due to the planning arrangement,

Inputs Outer Hebrides Kit Study 116m2

Areas

Floor	114.35	
North Wall	40.00001	8
South Wall	40	8
East Wall	56.9045	8
West Wall	56.70979	8
Floor Slab	141.4099	63.23
Roof	187.8779	
party Wall Roof WEST	0	
party Wall Roof EAST	0	

Windows

		Width	Height	No
North Windows	1	2.05	2.05	1
	2	0	0	0
	3	0	0	0
	4	0	0	0
East Windows	1	0	0	0
	2	3.05	2.05	1
	3	1.05	1.15	1
	4	1.5	2.05	1
South Windows	1	1.15	1.15	1
	2	1.05	1.15	1
	3	0	0	0
	4	0	0	0
West Windows	1	1.05	1.15	2
	2	0.6	2.05	1
	3	0	0	0
	4	0	0	0
Horizontal Windows		0	0	0
		0	0	0
		0	0	0
		0	0	0
Door		0.9	2.1	2

Volumes

Enclosed (Gross Volume)	555.7247	272.885	231.5068
Ventilation Volume	285.875	285.875	
Airtightness Rate	0.6		

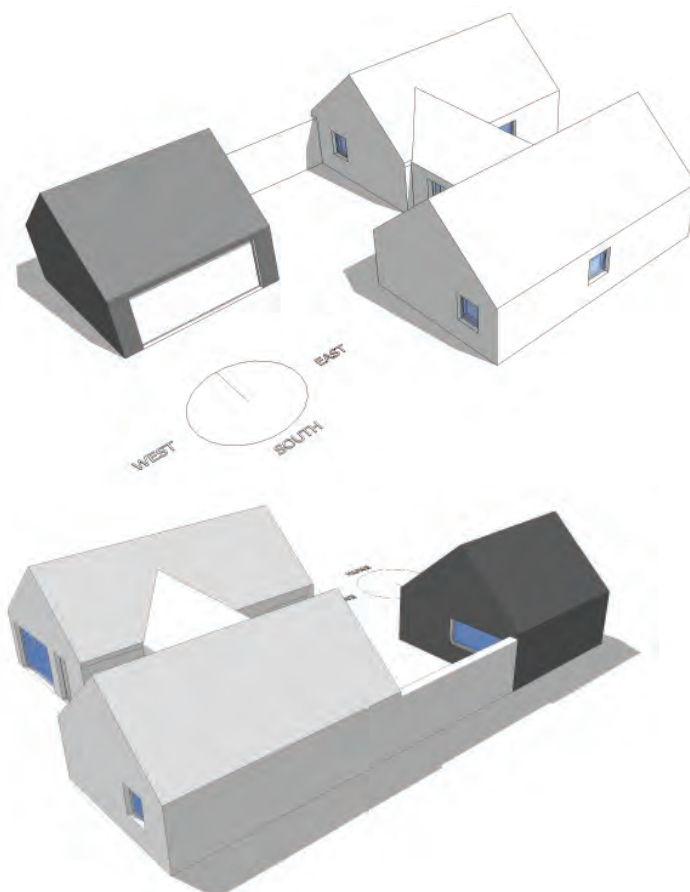


Figure 168- Proctor and Matthews Outer Hebrides Kit House Inputs & Model

limited the extent of the optimisation. Further modification to this house type in the west of Scotland would require significant alterations to the planning. The current changes made to the design of increasing the size of the south facing windows should improve the overall spatial quality of the interior whilst greatly lowering the SSHD.

7.4.5. Proctor and Matthews Architects, Outer Hebrides Kit Study

[Figure 168]

Orkney Results

SSHD: 30kWh/(m²a)

HL: 10.02W/m²

West of Scotland (WOS) Results

SSHD: 36.85kWh/(m²a)

HL: 13.87 W/m²

Performance Analysis

This house type has a significant amount of exposed surface area due to its fragmented clustered arrangement. The house has 525m² exposed surface area in comparison to the prototype house at 371m².

It is also 5m² higher than the Boreraig house of a similar arrangement. The high surface area of walls, roof and ground floor account for the majority of the heat losses. The distribution of windows does not give the building a clear orientation for solar gain which is not beneficial in terms of SSHD. This is reflected in the low window heat balance of 871 kWh in comparison with Boreraig at 3510 kWh. However, the extremely low percentage of south facing glazing (6% of façade) should allow for significant alteration in the optimisation study to significantly reduce the SSHD. Similar to other buildings in the study small windows create high SSHD requirements, but lower heat loads. The design performs well in terms of heat load, the Orkney heat load provides a requirement that meets the Passivhaus standard with no alteration.

SSHD Improvement Study

Orientation alteration

The current orientation or the rotation of +90° and reconfiguration of the dining and kitchen space appear to create the most suitable plans to maximise solar gain. The entrance has been designed to face the access road for the courtyard, so the design's orientation attempted to respond to varying site constraints. However for the purpose of the study this will be disregarded. The optimal orientation was found to be:

- Orientation +100°

This change of orientation optimises the design for SSHD in both climates. This improves the SSHD to 24.94 kWh/(m²a) in Orkney and in 31.42 kWh/(m²a) WOS. The extra 10° from due south will increase the exposure to the afternoon sun on the kitchen window. This orientates the larger dining room window to face south therefore increasing the solar gain from 23kWh/(m²a) to 29 kWh/(m²a) in Orkney and from 26kWh/(m²a) to 34 kWh/(m²a) in WOS. The heat losses are static in both cases. The SSHD increases very slightly when orientated due south.

East Window Increase SSHD Improvement

As the orientation study demonstrated a lower SSHD result when orientating the building +100°. The previous east facing windows are now almost south facing. This first study increases the window area on this elevation, this would require creating a large opening to the bedroom and is therefore not a feasible alteration to the plan.

- East Window Area Increase 18% to 33% of east elevation

Significantly increasing the small bedroom window reduces the SSHD in Orkney by 3.5 kWh/(m²a) and 6.13 kWh/(m²a) in WOS. The modified opening sizes now represent around 33% of the original east orientation. To increase this figure further would be more invasive to the planning and design and difficult to achieve due to the gable elevation and area of the wall opening into the space..

Original Orientation South Glazing Increase

SSHD Improvement Study 2

This study retains the original orientation, maximises the openings to the original south elevation and

removes the north opening into the living room. This lost day lighting can be replaced with increased south glazing. The removal of north facing windows and increase of south facing glazing to the whole elevation continues to lower the SSHD. However this scale of glazing is not practical. A more viable alteration is the removal of all north openings and a large increase to the area of the south façade order to reduce the SSHD.

- Removal of north openings
- Increase South Single 1.15x1.15m window to 2x 4.2x2.05m

This leads to a SSHD figure of 22.8 kWh/(m²a) in Orkney (from 30kWh/(m²a)) and 24.5 kWh/(m²a) in WOS (from 36.85kWh/(m²a)) This variation increases the heat load slightly to 11.2 W/m² in Orkney. It decreases the HL by almost 1 W/m² to 12.9 W/m² in WOS. The decrease is due to the dramatically increased solar heat gains cancelling out the increased losses. To further reduce SSHD, It is possible to reduce the SSHD in the West of Scotland to 23.7 kWh/(m²a) from 24.5 kWh/(m²a) by removing all but the 3.02x2.05m windows from the east and west elevations but this would make the plan unusable. Increasing the south facing glazing is the most beneficial for the SSHD whilst working well with the plan layout.

Orientation Study 2

Further alteration to the orientation of the improved type by +20° has a small beneficial effect in both climatic regions with a 0.28 kWh/(m²a) saving in Orkney and 0.37 kWh/(m²a) saving in the WOS. This is due to the large east facing window slightly increasing the solar gain available.

WOS Fabric Performance Study HL

In order for the improved design to meet the Passivhaus requirement for heat load in the WOS climate the U-value would need to change from 0.157 W/m² to 0.1 W/m², the same figure as the original Clousta type in the WOS from the previous study.

InputsIMP WOS OHebr South SSHD					
Areas					
Floor	114.35				
North Wall	40.00001	8			
South Wall	40	8			
East Wall	56.9045	8			
West Wall	56.70979	8	Perimeter		
Floor Slab	141.4099			63.23	
Roof	187.8779				
party Wall	0				
party Wall	0				
Windows					
	Width	Height	No	Dev	Nrth
North Wind	2.05	2.05	0	1	
2	0	0	0	1	
3	0	0	0	1	
4	0	0	0	1	
East Wind	0	0	0	3	
2	3.05	2.05	1	3	
3	1.05	1.15	1	3	
4	1.5	2.05	1	3	
South Wind	2.05	4.2	2	2	
2	1.05	1.15	1	2	
3	0	0	0	2	
4	0	0	0	2	
West Wind	1.05	1.15	2	4	
2	0.6	2.05	1	4	
3	0	0	0	4	
4	0	0	0	4	
Horizontal	0	0	0	0	
	0	0	0	0	
	0	0	0	0	
	0	0	0	0	
Door	0.9	2.1	2		
Volumes					
Enclosed	555.7247	272.885	231.5068	40.23405	11.098
Ventilation	285.875	285.875			
Airtightness	0.6				

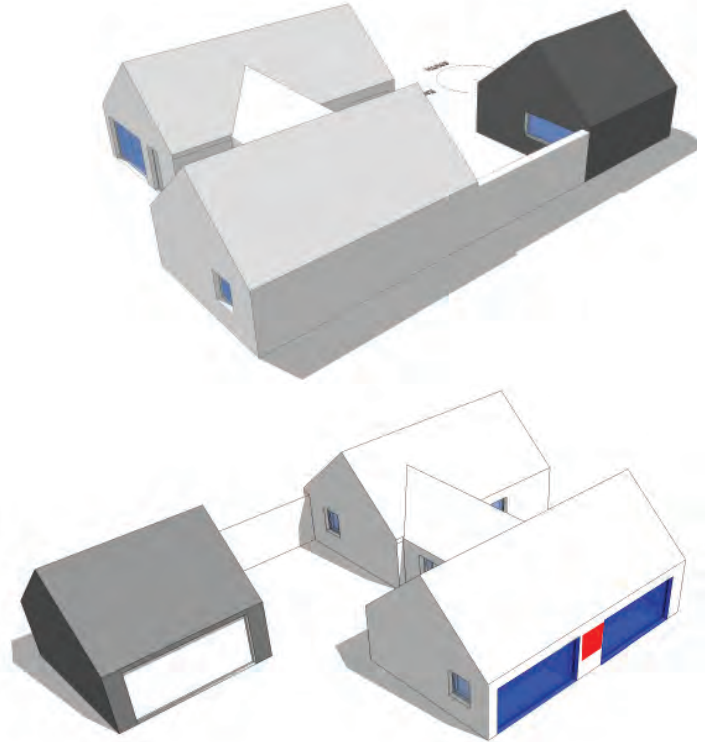


Figure 169- Proctor and Matthews Outer Hebrides Kit House Optimised Model

Proctor and Matthews Summary

[Figure 169]

Orkney Optimised Results

SSHD: 22.52kWh/(m²a)

HL: 11.2W/m²

West of Scotland Optimised (WOS) Results

SSHD: 24.13 kWh/(m²a)

HL: 12.9 W/m²

The specific optimisation for Orkney and WOS was attempted however there was negligible variation in the SSHD optimisations.

The redesign of the elevations from the previous alterations is optimal when retaining the existing plan. The significant alterations made to this type illustrate the difficulties in achieving ultra-low SSHD when using a house type with an inefficient plan layout with a high exposed surface area. In order to reduce the SSHD to Passivhaus levels the fabric performance increase would be significant. However due to the small openings the heat load performance of the original design meets the Passivhaus requirements in Orkney and would require a relatively large increase in fabric specification in the WOS.

7.4.6. NORD, Stone House Detached House (111m² End Model)

[Figure 170]

Inputs NORD Single House (End Model)

Areas

Floor	110.8021	
North Wall	51.975	8
South Wall	48.34668	8
East Wall	65.51766	8
West Wall	61.2847	8
Floor Slab	98.2025	52
Roof	109.0493	
party Wall Roof WEST	0	
party Wall Roof EAST	0	

Windows

WS		Width	Height	No	Dev Nrth
North Windows		1.1	2.1	1	1
	2	0.9	2.1	2	1
	3	2.5	2.1	2	1
	4	0	0	0	1
East Windows 1		3	2.1	1	3
	2	0.9	2.1	1	3
	3	1.9	3.1	1	3
	4	0	0	0	3
South Windows		2.5	1.6	1	2
	2	0.8	1.6	1	2
	3	0	0	0	2
	4	0	0	0	2
West Windows 1		0	0	0	4
	2	0	0	0	4
	3	0	0	0	4
	4	0	0	0	4
Horizontal Windows		0	0	0	0
		0	0	0	0
		0	0	0	0
		0	0	0	0
		0	0	0	0
Door		1	2.25	2	

Volumes

Enclosed (Gross Volume)	439.6043	
Ventilation Volume	277	277.0054
Airtightness Rate	0.6	

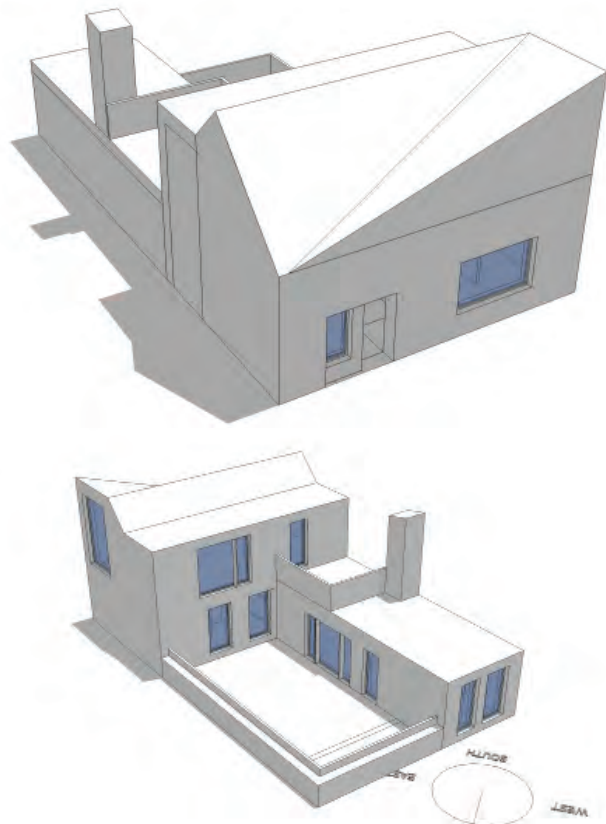


Figure 170-NORD Single House (End Terrace Model) Inputs & Model

Orkney Results

SSHD: 28.8 kWh/(m²a)

HL: 11.96 W/m²

West of Scotland (WOS) Results

SSHD: 32.5 kWh/(m²a)

HL: 14.26 W/m²

Performance Analysis

The NORD stone house has the highest SSHD of the houses with more modern design principles such as large areas of glazing. The SSHD is 20 kWh/(m²a) higher than the 107m² prototype in Orkney. It also has the highest heat load out of all of the designs in the study. The large expanse of glazing on the north east facing gable reduces overall SSHD and heat load efficiency. This combined with the complicated volumetric arrangement allows for significant heat losses through the envelope and poor performance. The exposed surface area is 439m² which is not the highest of the study but is 69m² more than the 107m² prototype. The high heat load and SSHD performance figures of the NORD designs illustrate the implementation of a clear

design concept with little or no thought for energy efficient design principles.

Orientation alteration

The orientation of the project is not optimal because many of the living spaces and therefore the larger areas of glazing face north, west or east and are shaded from the south by the main volume of the building. The study shows that changing the orientation creates significant SSHD reductions

- 150° From North (Orkney)
- 140° From North (WOS)

The alterations reduce the heating demand by 9 kWh/(m²a) in Orkney and 11.5 kWh/(m²a) in the West of Scotland. The orientation results in the gable and courtyard facing almost south west. The heat balance of the windows illustrates gains from the gable window and the windows surrounding the courtyard. The overall window heat balance has improved to 3410 kWh from 1032 kWh per year. The SSHD figures are 19.7 kWh/(m²a) in Orkney and 20.1 kWh/(m²a) in the West of Scotland. The heat load figures reduce slightly, 10.9 W/m² in Orkney and 12.3 W/m² in the West of Scotland. The significant decrease in SSHD due to the alteration of orientation is not enough to reduce SSHD to ultra low energy levels but would significantly reduce energy costs.

Fabric Improvement Study

SSHD West of Scotland

The removal of the north west facing windows around the front door (now north east facing) make little difference to the SSHD. Their removal only contributes around 1 kWh/(m²a) in both climatic regions. The same is true for increasing the gable window from 5.9m² to 9.3m². These increases would be to the detriment of the space and design quality and therefore do not represent a valid approach.

- Increasing south east glazing from 16.6m² to 25.4m²

Reduces the SSHD by 2.4 kWh/(m²a) (WOS) but only 0.7 kWh/(m²a) in Orkney. This increase in glazing would not be a viable option in Orkney due to the expense of building materials. These alterations to the elevation are significant therefore the benefit between costs and increase performance will be minimal. Due to the significantly altered elevation a small change in orientation offers more gains.

- 170° From North (WOS)

Reduced the SSHD to 17.9 kWh/(m²a) in the West of Scotland. The heat load in the same climate with the alteration is reduced by 2 W/m² in the west of Scotland at 12.2 W/m².

Inputs Imp WOS NORD Single House

Areas

Floor	110.8021	
North Wall	51.975	8
South Wall	48.34668	8
East Wall	65.51766	8
West Wall	61.2847	8
Floor Slab	98.2025	52
Roof	109.0493	
party Wall	0	
party Wall	0	

Windows

	Width	Height	No	Dev Nrth
North Wind	3.1	2.1	1	1
2	1.65	2.1	2	1
3	4	2.1	1	1
4	0.9	2.1	2	1
East Wind	3	2.1	1	3
2	0.9	2.1	1	3
3	1.9	3.1	1	3
4	0	0	0	3
South Wind	2.5	1.6	1	2
2	0.8	1.6	1	2
3	0	0	0	2
4	0	0	0	2
West Wind	0	0	0	4
2	0	0	0	4
3	0	0	0	4
4	0	0	0	4
Horizontal	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
Door	1	2.25	2	

Volumes

Enclosed	426.6232
Ventilation	277
Airtightness	0.6

NORD WOS Single House Improved Inputs

SSHD Orkney

As the West of Scotland fabric optimisation study illustrated, the major increase in glazing to the south east glazing only has a small effect. The alteration of the windows, both removal and increase in scale will only have the maximum reduction of around 1 kWh/(m²a).

NORD Single House Summary

[Figure 171]

[Figure 172]

[Figure 173]

Orkney Optimised Results

SSHD: 19.7kWh/(m²a)

HL: 10.9 W/m²

West of Scotland (WOS) Optimised Results

SSHD: 17.9 kWh/(m²a)

HL: 12.2 W/m²

Significant alteration to the design has a marked effect on thermal performance. Due to the large area

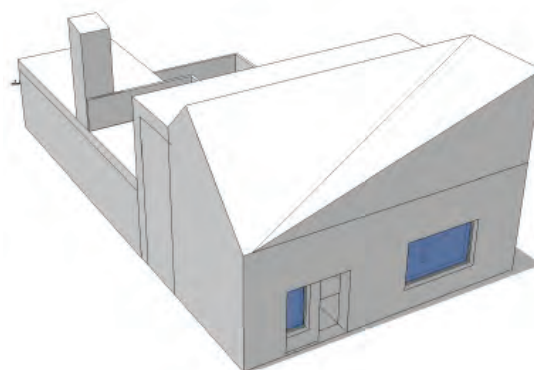


Figure 171- NORD Single House (End Terrace Model) Optimised Model Orkney and West of Scotland Rear Elevation

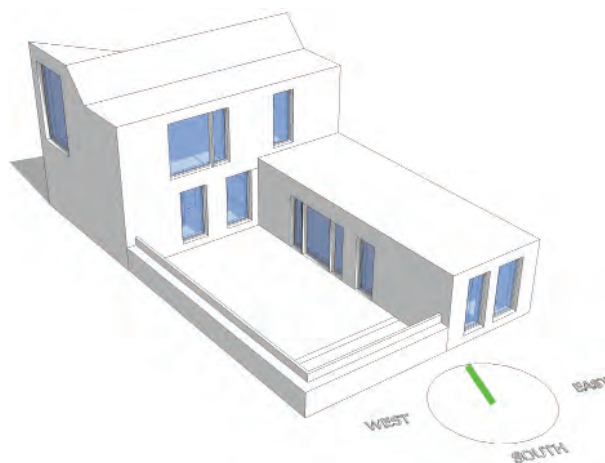


Figure 172- NORD Single House (End Terrace Model) Optimised Model Orkney

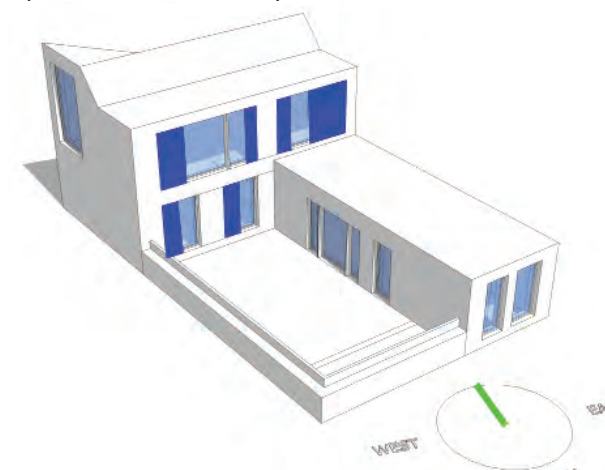


Figure 173- NORD Single House (End Terrace Model) Optimised Model West of Scotland

of exposed surface area the design is still unable to meet the Passivhaus criteria for SSHD. Through an increase in thermal envelope the design would be able to meet the Passivhaus requirement for heat load in Orkney. Meeting the heat load requirement in the West of Scotland would require significant increases to the specification. This example illustrated the significant gains available through considered orientation. It is possible that this could be attributed to the way in which the design was developed to address the road in the initial Scottish Housing Expo competition entry. This demonstrates the importance of consideration of design concepts and an optimised solar and thermal arrangement.

7.4.7.NORD, Stone House (107m² Mid Terrace)

Inputs NORD Mid Terrace

Areas

Floor	110.8021	
North Wall	51.975	8
South Wall	34.965	8
East Wall	61.2847	18
West Wall	27.295	18
Floor Slab	98.2025	29.2
Roof	113.9387	
party Wall Roof WEST	33.9897	
party Wall Roof EAST	0	

Windows

	Width	Height	No	Dev Nrth	
North Windows	1.1	2.1	3	1	
2	0.9	2.1	2	1	
3	2.5	2.1	1	1	
4	0	0	0	1	
East Windows 1	0	0	0	3	
2	0	0	0	3	
3	0	0	0	3	
4	0	0	0	3	
South Windows	2.5	1.6	1	2	
2	0.8	1.6	1	2	
3	0	0	0	2	
4	0	0	0	2	
West Windows 1	3	2.1	1	4	
2	0.9	2.1	1	4	
3	0	0	0	4	
4	0	0	0	4	
Horizontal Windows	1	1.8	4	45	45
	0	0	0	0	
	0	0	0	0	
	0	0	0	0	
Door	1	2.25	2		

Volumes

Enclosed (Gross Volume)	426.6232	
Ventilation Volume	277	277.0054
Airtightness Rate	0.6	

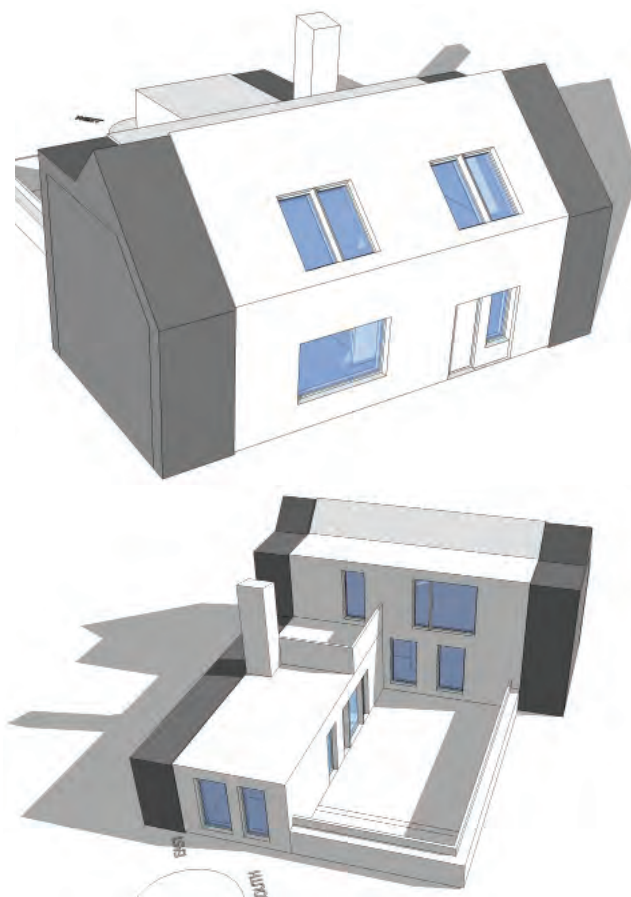


Figure 174- NORD Mid Terrace Model Inputs & Model

[Figure 174]

Orkney Results

SSHD: 21.8 kWh/(m²a)

HL: 11.0 W/m²

West of Scotland (WOS) Results

SSHD: 22.7 kWh/(m²a)

HL: 13.2 W/m²

SSHD Performance Analysis

The NORD mid terrace performs relatively poorly in comparison to the mid terrace 107m² prototype. In the WOS the SSHD increases by 7.7 kWh/(m²a). The reduced solar gains has an effect on this performance however fabric heat losses contribute around 3.7-4 kWh/(m²a) more than that of the 107m² (mid terrace) control prototype. The majority of these increased losses are from the roof and ground. This is reflected in the increased surface area of 319m² compared with the mid terrace prototypes 284m². The design does not lack large openings in fact the NORD design has a greater area of glazing than the prototype which also contribute to the increased losses. Optimisation of the orientation of the design will enable increased performance. However, the large openings of the design are spread across all of the exposed elevations therefore limiting the orientation optimisation exercise due to the low energy balance of the windows. The heat loads of this design are fairly low, this can be attributed to the building typology. The control HL is between 1W/m² (Orkney) and 2W/m² (WOS) lower than the NORD design.

Fabric Improvement Study

For the design to achieve the Passivhaus requirement for SSHD the following u-values would be required:

- Orkney - 0.082 W/(m²K) (from 0.137 W/(m²K))
- West of Scotland - 0.165 W/(m²K) (from 0.234W/m²)

The WOS value could be achieved through standard construction. However the Orkney u-value is significantly higher than the best practice requirement of 0.137 W/(m²K). The increases in u-values are considerably higher than the detached prototypes u-value to meet 15 kWh/(m²a). This reflects the designs low thermal performance.

Orientation

As stated in the analysis altering the orientation of the design has a beneficial effect on the SSHD. The optimised orientation for the WOS changes the building's courtyard from facing north east (-55 °) to almost due south (-160 °). It results in a 1.4 kWh/(m²a) reduction in heat demand resulting in an overall demand of 21.25 kWh/(m²a). The same alteration in the Orkney climate will produce a lower reduction of 1.1 kWh/(m²a) resulting in an overall SSHD of 20.6 kWh/(m²a). This small variation reflects the reduced solar gain available in Orkney.

SSHD West of Scotland Optimisation

As highlighted in the orientation optimisation the heat balance of the windows has a major effect on the SSHD of the design. Retaining the optimised orientation, the alteration of the glazing areas has a significant effect i.e. switching the location of the roof lights to the south facing roof

- Roof Light Alteration 180°

The SSHD in WOS reduces by 2.8 kWh/(m²a) to 18.4 kWh/(m²a). This has a lesser effect in Orkney (18.509 kWh/(m²a Orkney). In an extreme test removing both the north and west facing glazing it is possible to

reduce the SSHD of the altered type to 16.091 kWh/(m²a) in Orkney and 17.549 kWh/(m²a) in the WOS. Although almost reaching the Passivhaus requirement, this alteration would significantly impact on the quality of space.

A far more appropriate option for the altered type is to increase the glazing to the courtyard elevation (20° from south).

- Increase Courtyard Glazing 16m²- 25m²

This increase allows for the SSHD Passivhaus criteria to be met in the WOS, a 3.25 kWh/(m²a) reduction. The criteria is almost met in Orkney with an SSHD of 17.1 kWh/(m²a). Due to the alterations made to the model, the resultant design varies significantly from the original.

Inputs

NORD Mid Terrace Improved

NOTE -160 Orient

Areas

Floor	110.8021				
North Wall	51.975	8			
South Wall	34.965	8			
East Wall	61.2847	18			
West Wall	27.295	18	Perimeter		
Floor Slab	98.2025			29.2	
Roof	113.9387				
party Wall Roof WEST	33.9897				
party Wall Roof EAST	0				

Windows

		Width	Height	No	Dev Nr
North Windows	1	1.1	2.1	3	1
	2	2.4	2.1	2	1
	3	4	2.1	1	1
	4	0	0	0	1
East Windows	1	0	0	0	3
	2	0	0	0	3
	3	0	0	0	3
	4	0	0	0	3
South Windows	1	2.5	1.6	1	2
	2	0.8	1.6	1	2
	3	0	0	0	2
	4	0	0	0	2
West Windows	1	3	2.1	1	4
	2	0.9	2.1	1	4
	3	0	0	0	4
	4	0	0	0	4
Horizontal Windows	1	1.8	4		
	0	0	0	0	
	0	0	0	0	
	0	0	0	0	
Door	1	2.25	2		

Volumes

Enclosed (Gross Volume)	426.6232		
Ventilation Volume	277	277.0053	
Airtightness Rate	0.6		

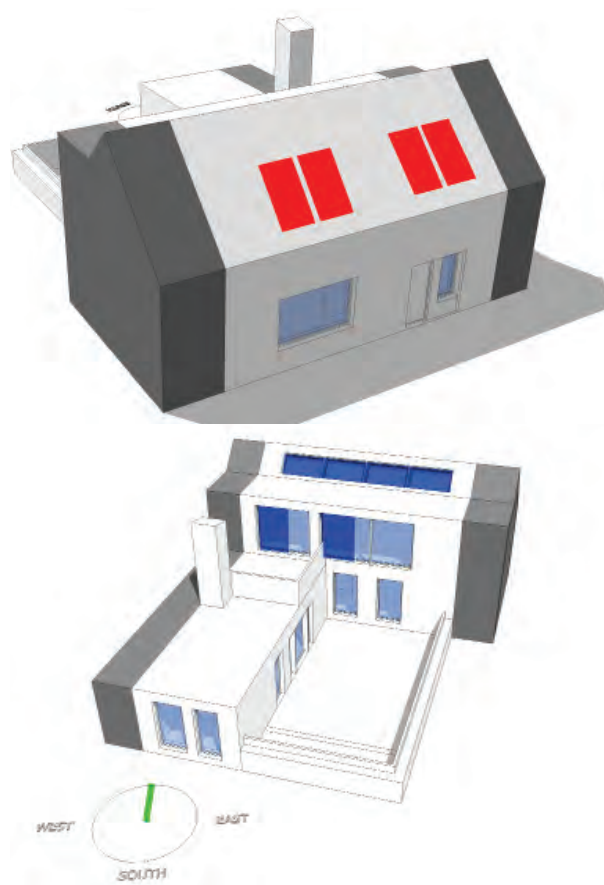


Figure 175- NORD Mid Terrace Model Optimised Model

NORD Mid Terrace Summary

[Figure 175]

Orkney Optimised Results

SSHD: 17.1kWh/(m²a)

HL: 9.4 W/m²

West of Scotland Optimised (WOS) Results

SSHD: 15.1kWh/(m²a)

HL: 12.2 W/m²

The inefficiencies of the building form have a significant impact on the application of Passivhaus on this design. Through significant modification of the elevations, openings and orientation it is possible to achieve the Passivhaus criteria without alteration to the building specification. However this has had a significant effect on the design and somewhat compromises the original design intent.

7.4.8. NORD, Stone House (111m² End Terrace)

Inputs NORD End Terrace\Semi

Areas

Floor	110.8021		
North Wall	51.975	8	
South Wall	48.34668	8	
East Wall	65.51766	8	
West Wall	61.2847	18	Perimeter
Floor Slab	98.2025		35.45
Roof	109.0493		
party Wall Roof WEST	0		
party Wall Roof EAST	0		

Windows

		Width	Height	No	Dev Nrth
North Windows	1	1.1	2.1	1	1
	2	0.9	2.1	2	1
	3	2.5	2.1	2	1
	4	0	0	0	1
East Windows 1	1	3	2.1	1	3
	2	0.9	2.1	1	3
	3	1.9	3.1	1	3
	4	0	0	0	3
South Windows	1	2.5	1.6	1	2
	2	0.8	1.6	1	2
	3	0	0	0	2
	4	0	0	0	2
West Windows 1	1	0	0	0	4
	2	0	0	0	4
	3	0	0	0	4
	4	0	0	0	4
Horizontal Windows	1	0	0	0	0
	2	0	0	0	0
	3	0	0	0	0
	4	0	0	0	0
Door	1	2.25	2		

Volumes

Enclosed (Gross Volume)	439.6043	
Ventilation Volume	277	277.0054
Airtightness Rate	0.6	

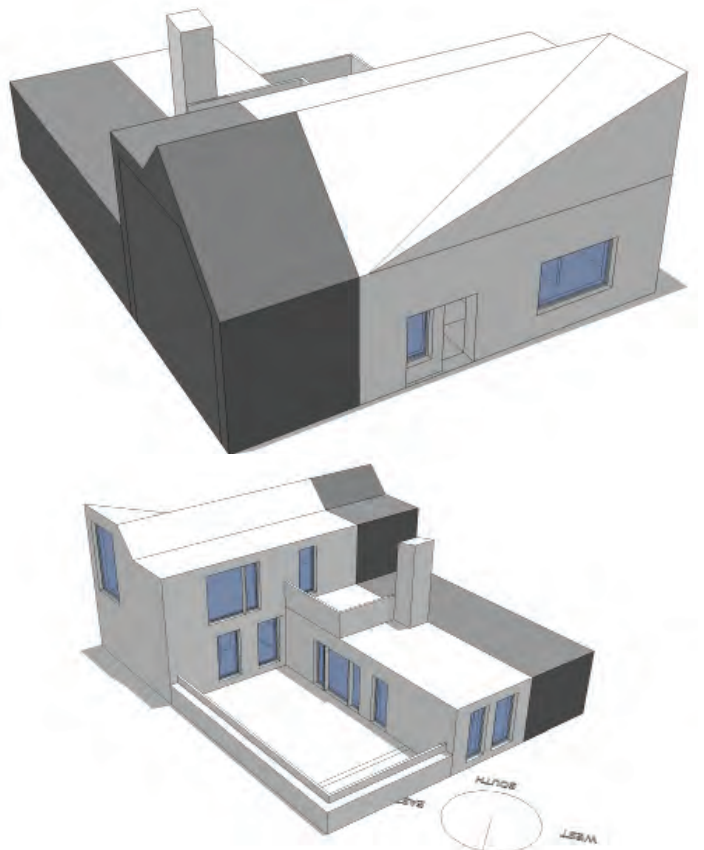


Figure 176- NORD End Terrace Inputs & Model

[Figure 176]

Orkney Results

SSHD: 27.6 kWh/(m²a)

HL: 11.8 W/m²

West of Scotland (WOS) Results

SSHD: 30.7 kWh/(m²a)

HL: 14 W/m²

Optimisation Note

This design performs very similarly to the NORD single house model as they use almost identical building forms. The only variation will be reductions in heat lost through the sheltered gable wall. Therefore the optimisation study suggests the use of the same alterations. The results for the house type produce the following results:

NORD End Terrace Summary

[Figure 177]

[Figure 178]

[Figure 179]

Orkney Optimised Results

SSHD: 18.9kWh/(m²a)

HL: 10.7W/m²

West of Scotland (WOS) Optimised Results

SSHD: 19.6kWh/(m²a)

HL: 12.1W/m²

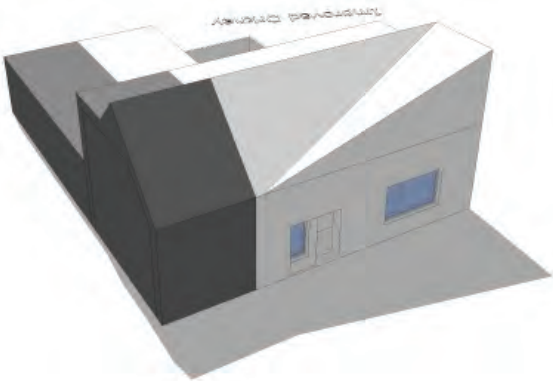


Figure 177- NORD End Terrace Optimised Model Orkney and West of Scotland Rear Elevation

Therefore the same alterations of virtually the same house type with a sheltered gable wall will receive simpler proportional reductions but not meet the Passivhaus requirements.

Inputs Imp NORD End Terrace -160 degrees				
Areas				
Floor	110.8021			
North Wall	51.975	8		
South Wall	48.34668	8		
East Wall	65.51766	8		
West Wall	61.2847	18	Perimeter	
Floor Slab	98.2025			35.45
Roof	109.0493			
party Wall	0			
party Wall	0			
Windows				
	Width	Height	No	Dev Nrth
North Wind	1.1	2.1	1	1
2	0.9	2.1	2	1
3	2.5	2.1	2	1
4	0	0	0	1
East Wind	3	2.1	1	3
2	0.9	2.1	1	3
3	1.9	3.1	1	3
4	0	0	0	3
South Wind	2.5	1.6	1	2
2	0.8	1.6	1	2
3	0	0	0	2
4	0	0	0	2
West Wind	0	0	0	4
2	0	0	0	4
3	0	0	0	4
4	0	0	0	4
Horizontal	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
Door	1	2.25	2	
Volumes				
Enclosed	439.6043			
Ventilation	277	277.0054		
Airtightness	0.6			

NORD Orkney End Terrace Improved Inputs

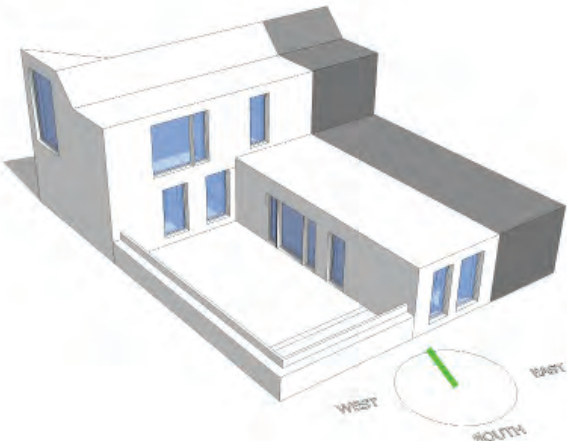


Figure 178- NORD End Terrace Optimised Model Orkney

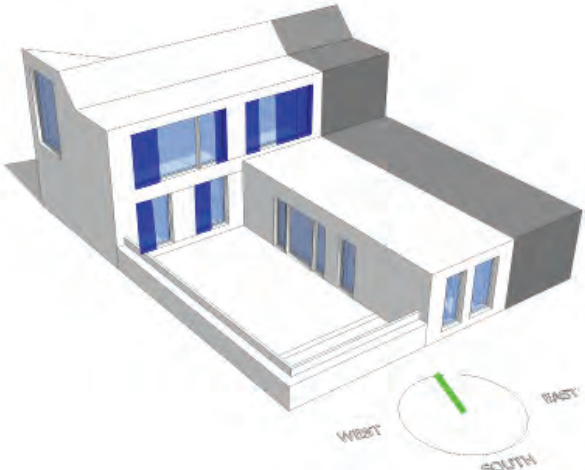


Figure 179- NORD End Terrace Optimised Model West of Scotland

7.4.9. Optimisation Conclusions

[Figure 180] SSHD Exemplars- Optimised

[Figure 181] Percentage Reduction in SSHD

[Figure 182] Heat Load Exemplars- Optimised

Firstly the optimisation studies were challenging due the lack of a simple one size fits all approach for the optimisation process due to the variation of the prototypes. The methods and particular variables altered such as the selected fabric performance studies highlight the implications of different methods possible to achieve ULEH. The further alteration of the plan layout, roof design and typology would lead to significant reductions in SSHD and HL however this study could have a multitude of possible variations.

In all cases, the study has made improvements to either the heat load and SSHD of the exemplar designs. In some cases, the designs required significant alteration to lower SSHD due to their lack of suitability for ultra-low energy performance. The [Figures 180 and 182] illustrate the original performance of all of the types (faded out in graph) and the optimised performance. The [Figure 181] shows the increase in SSHD performance of the optimised exemplars. This study demonstrates the large effect that the initial building design has on not only the initial SSHD, but a limiting factor of the possible improvements to SSHD through simple optimisations. The designs which performed badly in SSHD generally saw larger reductions in SSHD. One anomaly was the R2 House although performing extremely well in heat load also saw a large reduction in SSHD on Orkney of 31% reducing its SSHD to the required 15 kWh/(m²a) due to its compact form.

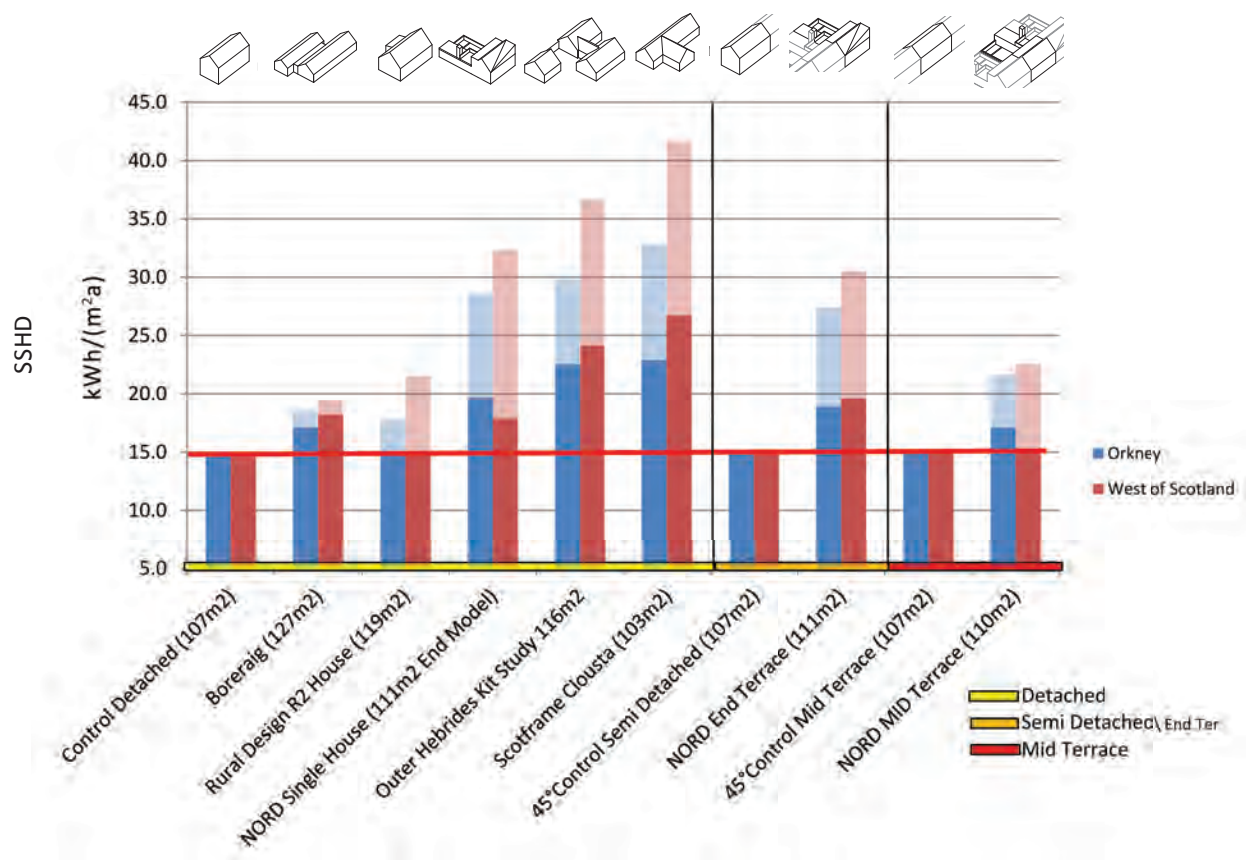


Figure 180- SSHD Exemplars- Optimised

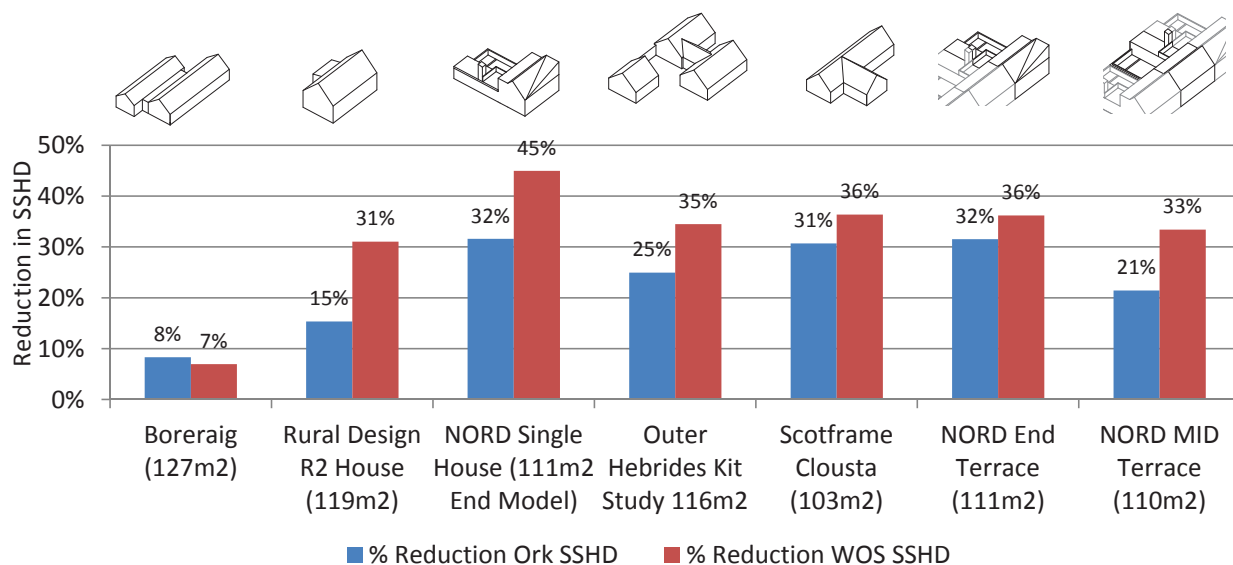


Figure 181- Percentage Reduction in SSHD

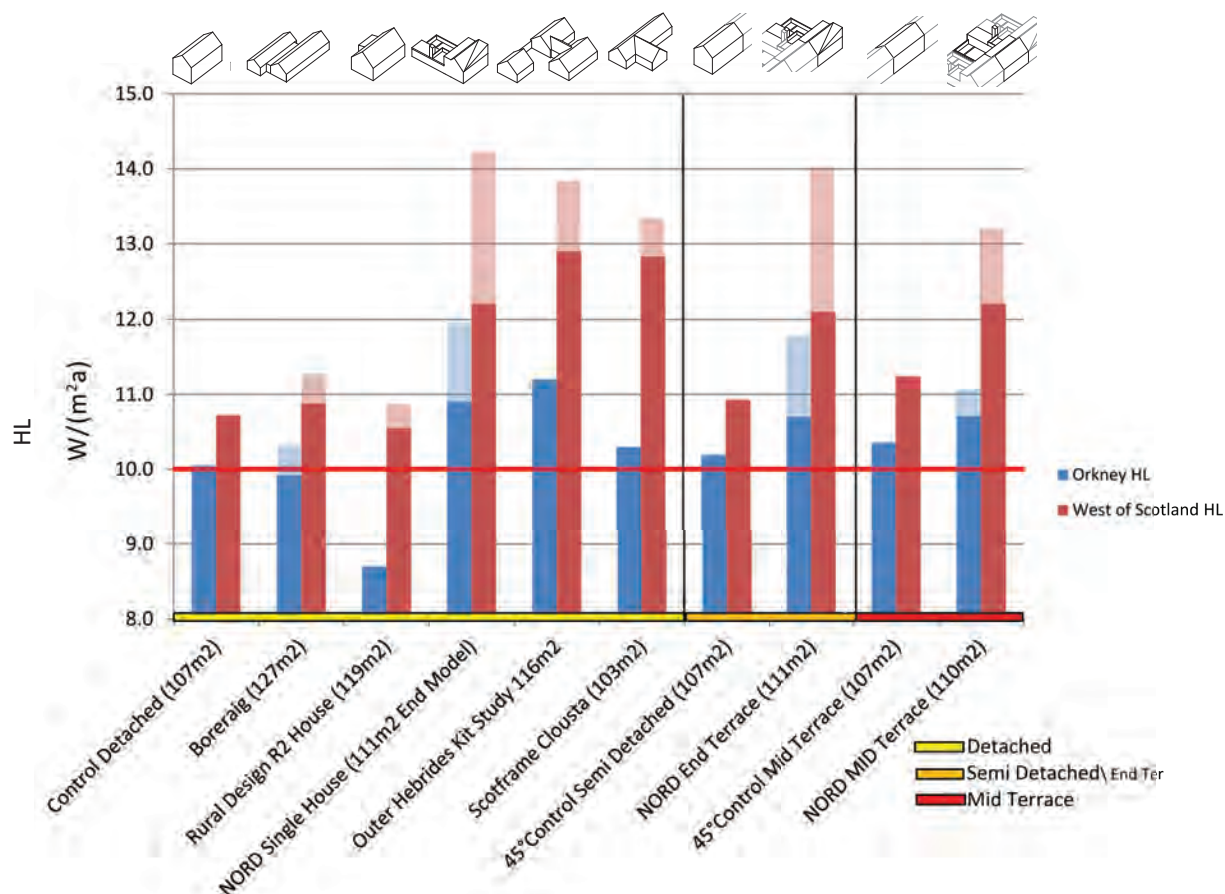


Figure 182- Heat Load Exemplars- Optimised

This study reinforces the key drivers of the design of energy efficient dwellings are the energy balance of windows and the exposed surface area of the form. Exemplarily designs with high levels of exposed surface area and low window energy balance can be optimised to a certain extent through improvement of glazing design and orientation but, large areas of exposed surface will generate prohibitively large heat losses when trying to achieve lower SSHD levels.

The Clousta illustrates significant reductions in SSHD with one single but significant glazing increase to the south, which reduced the SSHD by more than a third, 36% in the West of Scotland. The orientation is also a significant factor and optimising this is one of the key factors in influencing the energy balance of the windows. The orientation analysis of the ultra-low energy prototype from the first research project in section 6.5.2 (2B) revealed a significant increase in SSHD with only small variations. The exemplary design study confirms that optimisation of orientation can only significantly lower SSHD when the large expanses of glazing design are mainly focused on one façade and can be orientated to the south. The house designs that have little solar gain reliance such as the Scotframe designs generally have low heat loads due to small areas of glazing and can accommodate larger variations of orientation with less of an effect on thermal performance. This is in contrast to the very similar NORD end terrace/single house model with its large gable window, which is more sensitive to orientation and can have a much larger effect on SSHD. This end terrace model also affirms the findings in Chapter 6, which state the importance of the optimal orientation when optimising SSHD. The NORD single house model requires significant alteration to elevational design and orientation but it demonstrates the largest reduction in SSHD with 45% in the West of Scotland and 32% in Orkney due to the significant inefficiencies of the original design. The Outer Hebrides Kit Study house and the NORD prototype highlights interesting findings in the orientation optimisation study. The increase from south facing ($\sim 10\text{-}20^\circ$) orientation allows for marginal increases due to openings on the side elevations. Due to the inefficiencies of many of the types, changes to the building envelope to accommodate regional design have little effect when trying to achieve maximum efficiency. The regional climatic variation has more impact when the most efficient approach is not possible such as in the case of orientation constraints or focus on north facing views. In all cases the impact of less efficient design has a smaller impact in the Orkney climate which can be attributed to the compensation of the higher thermal performance created by the weighted u-values.

To quantify and illustrate the effect that the weighted u-values have on the exemplary and optimised designs a separate study was performed. In addition to the existing results for the Scotframe Clousta design and improved design in Orkney, the weighted u value for the UK average climate data is used in the Orkney climate region for the two designs [Figure 183]. This study illustrates the increase in SSHD when not using the weighted u-value on the Clousta type. This is around 12 kWh/(m²a) on the original design and 9 kWh/(m²a) on the optimised design. Due to the harsh climate in combination with the inefficient building form of the original design the weighted u-value required to meet the Passivhaus 15 kWh/(m²a) SSHD requirement in Orkney is 0.032 W/(m²K), resulting in a thickness of around 1060mm. The improved type would require a value of 0.055 W/(m²K) and a thickness of 640mm. The inefficient building envelopes of this type and other exemplars and their increased SSHD in harsh climates such as Orkney demonstrates for the increased need building more efficient build design and typologies. The increased requirement in wall thickness if the SSHD

was to be met (irrespective of heat load performance) is impossible to achieve. In many of the traditionally themed design examples, such as the Scotframe developed house types (including Proctor and Matthews) have high SSHD but the HL requirement is much closer to achieving the Passivhaus target of 10 W/m². The results demonstrate that if a design with smaller windows is required, this can still be suitable for Passivhaus certification using the heat load. Using the heat load for certification in these types is the most feasible option as the SSHD figures are so high even with the high performance envelope and decreases in SSHD through the optimisation study.

However, the heat load certification in PH

is based on the thermal capacity of air and its ability to transport enough heat through the MVHR system.

This then allows for the removal of a heating system as the heating can be supplied through ventilated air.

With a low heat load and high SSHD, the increase in annual energy use may not cover the initial reduction in capital costs of not installing a traditional heating system. Also the losses created by thermal bridging are exaggerated with complex detailing. Thermal Bridging is omitted in this study, however heat losses through detailing could have a detrimental effect on the heat load requirement. The effects of heat losses through inefficient, complex detailing would affect examples like the Outer Hebrides kit house which has many complex junctions.

The Rural Design optimisation study illustrates that regional approaches to the design of building are almost certainly required if lower energy use in rural housing is to be achieved. However the optimal approach when lowering SSHD is very similar across different regions. It is in cases when the optimal approach is not suitable, variations from best practice have different effects in regions. The Dualchas Boreraig, Rural Design R-House in particular demonstrates the relevance of simple compact forms, south orientation, reduction of north glazing which are widely associated with traditional forms. When these principles are combined with modern elevational designs they can be a viable option for ultra-low energy housing. These exemplar designs performed significantly better than designs in which intuitive solar orientation seemed to have been ignored such as the NORD examples, and better than the Scotframe interpretations of traditional of house designs in which efficient window orientation is ignored and window sizing is reduced to minimum regulatory requirements to reduce specification costs. This suggests that the use of some traditional design cues are suitable for use in the development of both ULEH and can be appropriate in rural areas. In particular the compact roof in the roof form coupled with an optimised south facing façade of the R-House led to high levels of performance as a detached design. This design would be suitable for use as a traditional terrace

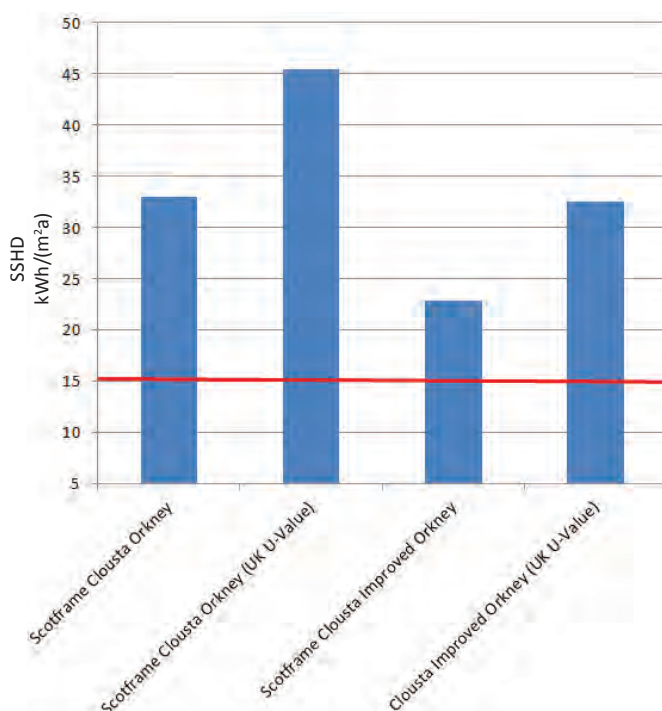
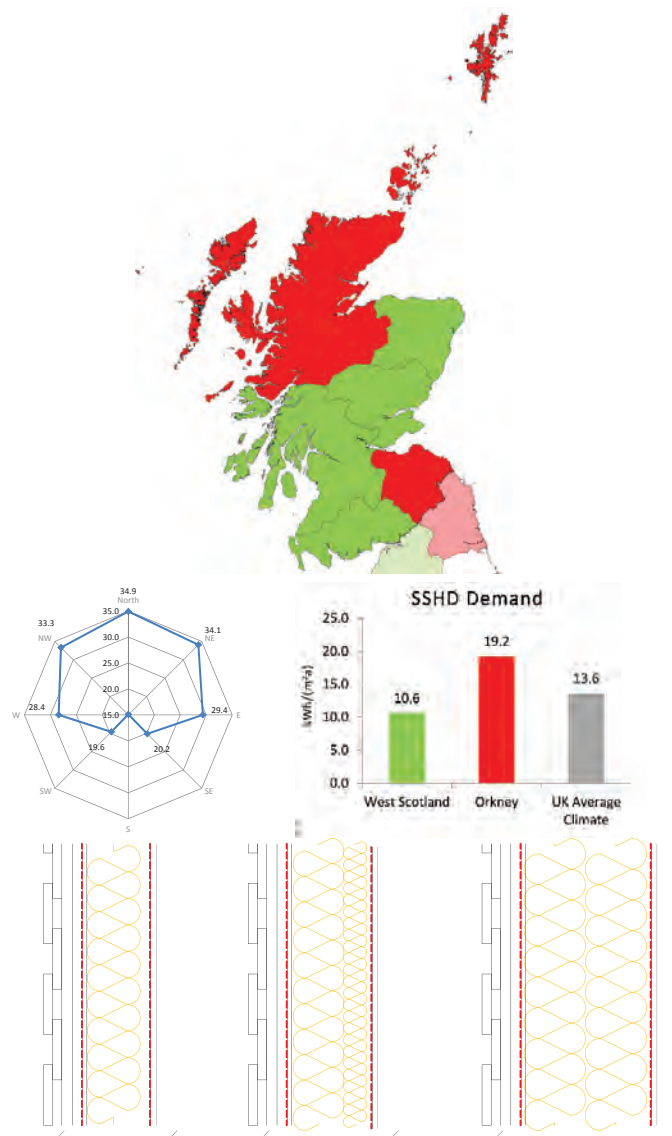


Figure 183- SSHD Clousta Orkney with UK Average U-Values

typology or as a group of clustered houses would reduce SSHD and HL figures to minimal levels, whilst responding to rural areas. The selected traditional design cues share similar aims to established thinking for low energy housing such as reducing exposed surface area minimising losses through areas of glazing.

DISCUSSION AND CONCLUSIONS

Chapter 8



8. DISCUSSION AND CONCLUSIONS

The research has added to the quantitative knowledge base for the design of ULEH in Scotland and developed new qualitative knowledge across many areas in this field. The initial stages of the research determined a gap in the availability of knowledge and guidance for regional Scottish ULEH. The findings from the literature review suggested the requirement for knowledge in order to design and build low cost regional ULEH which are appropriate for rural contexts. There is also a lack of guidance and quantitative data for the design of ULEH across Scotland. In order to address these gaps a series of studies determine the energy performance of a range of housing designs in terms of SSHD and heat load using PHPP with BRE regional Scottish climate data. The initial studies in Chapter 6 determined the variance of SSHD due to the different Scottish climates and highlighted the requirement for regional solutions in legislation if estimated performance is to be achieved in practice. The later research studies in Chapter 6 illustrated the impact that the building form has on SSHD when deviating from best practice in Scotland along with the shortcomings of current legislative ZCH technical recommendations. The final studies in Chapter 7 determined the viability of some existing versions of exemplar designs for use as ULEH based on SSHD and heat load performance. Optimisation of these designs also demonstrated significant reductions in SSHD and heat loads by optimising glazing area and position. Throughout the research, the use and continued development of the customised PHPP and PHPP master file has proven to be an extremely flexible and useful research tool. The Excel underpinnings allowed for integration and linkages to the PHPP and have enabled the development of a certain degree of autonomy. The development of pull down menus for selecting designs increased speed and accuracy when compared with manual input. The research has led to the development of a new efficient research tool suitable for multiple regional climates and use with multiple design scenarios through adaption of the original PHPP software inputs and outputs whilst retaining the original accuracy of PHPP.

8.1. Legislation

Through an in depth analysis of current legislation and drivers, the requirement for more suitable rural homes was evident. There is a requirement for more rural housing due to the projected increase in rural population. There is a current necessity for more affordable housing which is less expensive to build and heat in order to reduce fuel poverty. The requirement is mirrored by the wider aims for Scottish Government targets whereby all new homes must be ZHC by 2016/17 and the European requirements for all new homes to be NZEB by the end of 2020. The space heating in UK represents around 66% of the homes total energy use in the UK, therefore is key in reducing energy demands. The analysis of current assessment methodology SAP reveals that current new homes have no requirement to consider regional climatic variation's effect on heating requirements. This, coupled with the generally harsher Scottish climatic conditions across much of rural Scotland, will increase heating demands. Current 'planning and design' legislation and best practice call for more appropriate designs and development models for rural areas. For many years, planning legislation and guidance have aimed to move away from typical mass-market housing development which employs standardised housing models and suburban planning layouts. The research revealed little evidence

of alternatives to mass market housing development styles and ultra-low or low energy rural housing appropriate for rural areas. The majority of rural ULEH were expensive one off houses which are Passivhaus Certified, as the ZCH definition for Scotland is not finalised.

8.2. Climatic Variation

Climatic Variation Across Scotland

The research findings from Study 1A highlights the requirement for regional solutions for ULEH. The study determines the large climatic variation across Scotland and uses BRE nine climatic regions to determine the effect on SSHD. The study revealed a maximum increase of 81% in SSHD between the West of Scotland and Orkney due to temperature differences and availability of solar gains. The impact of this variation on building fabric is discussed in Study 1B.

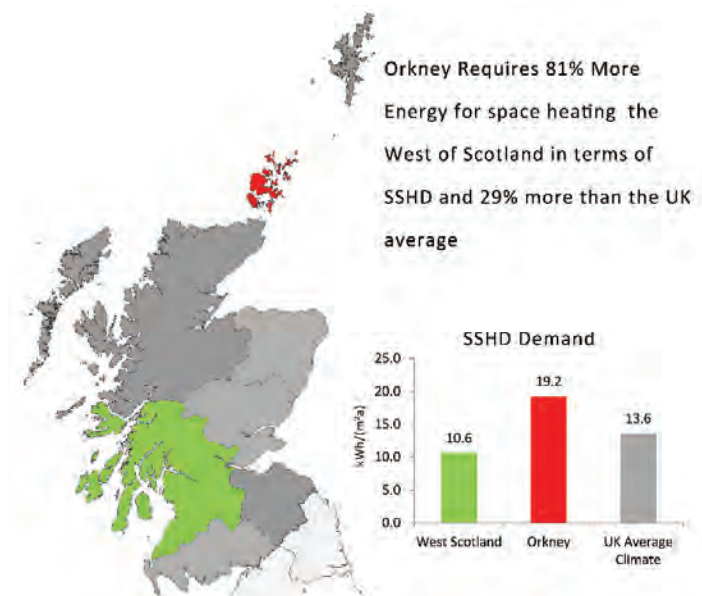


Figure 184- Orkney, West of Scotland and UK Average SSHD

UK Average and Scottish Regional Climatic Variation in SSHD

The research findings from Study 1B suggest that there will be short falls in predicted SSHD performance in the current and future regulatory analysis methodology, SAP. The SAP 2009 software uses a mean average of the UK's climate generated by the BRE to demonstrate regulatory compliance and heating cost estimates of both building regulations and ZCH. The SAP UK average climate data corresponds exactly to that of the Sheffield climate data. The SAP is also used to generate the FEES fabric specification to meet the ZCH requirements. Study 1B generated the equivalent UK average climate data sourced from the BRE to perform a climatic comparison with PHPP. The study revealed that many regions, particularly across rural areas (Borders, Western Isles and Highland regions), performed worse than the UK average in terms of SSHD, in some cases by more than 29% [Figure 184]. This figure will be higher in specific rural areas due to some sites having worse than regional average micro climate characteristics, such as areas at higher altitudes. The regional areas that performed worse than the UK average constituted a considerable proportion of rural

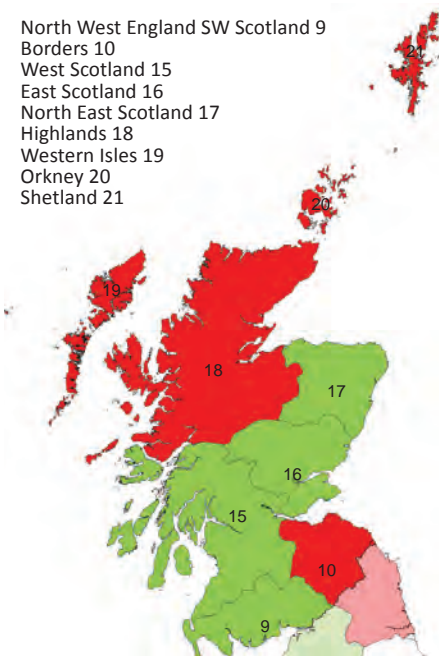


Figure 185- Climatic Regions with Higher SSHD than the UK average (red)

housing allocation in Scotland (these are highlighted in red in [Figure 185]). The SAP 2012 released in April 2014 uses the same climate data for regulatory compliance but uses regional data for heating cost estimates therefore giving the house holder a more accurate estimation of energy costs through the EPC supplied with the house. However, the fabric specification will remain static across Scotland and carbon emissions and energy performance will be higher in climates harsher than the UK average unless legislative requirements are exceeded. If the building legislation minimum fabric requirements and SAP were sensitive to regional climatic variations in Scotland, housing in rural areas would be more efficient and require the generation of more contextually responsive solutions.

8.3. Specification and Ventilation Losses

Weighted U-Values

The development of weighted u-values in Study 1B for use in later studies demonstrated the impact of the climatic variation when trying to achieve similar performance levels across Scotland. The resultant wall and roof thickness required an increased insulation thickness of around 149mm across the extremes of the Scottish Climate and around 110mm between Orkney and the UK average [Figure 186].

This increase is highly significant to construction cost, building design and detailing and is required

to normalise thermal performance. If regional specifications are implemented, increases in thermal

specification increase housing construction costs in some rural areas with harsh climates. The resulting improved SSHD performance is likely to demonstrate long term savings due to increasing fuel costs.

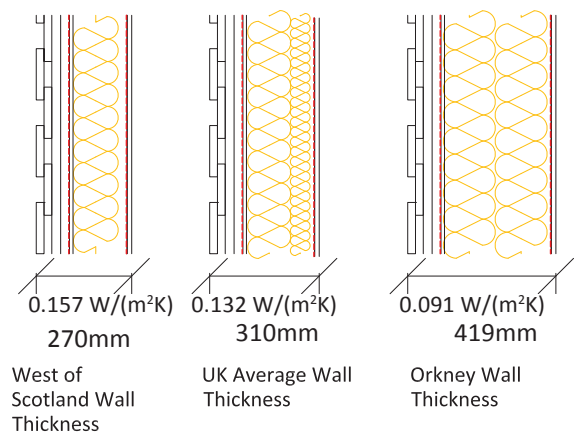


Figure 185- Wall thickness Comparison

ZCH Specification

The fabric performance of building elements for ZCH is determined by SAP and UK average climate data. Research Study 3B demonstrated that both the ZCH standards FEES and Advanced fabric specifications are inadequate for some regions across Scotland. Using the minimum ZCH fabric specification (FEES), the Orkney climate has a 9.2 kWh/(m²a) higher SSHD performance compared the UK average. The resultant SSHD figure is 33.7 kWh/(m²a), more than double that of a certified Passivhaus in the same area. The use of the best practice ZCH specification (Advanced) demonstrates its viability for ULEH, outperforming Passivhaus levels in the West of Scotland climate and complying with Passivhaus in the UK average climate. This study uses a best practice housing design therefore, if a less efficient housing design was to be used the heating requirement would be substantially higher in all cases. If the UK NZEB fabric specifications are determined through SAP using Average UK climate data, there will be a shortfall between estimated and actual performance in some areas of Scotland.

Ventilation Losses

The use of a MHVR system with high levels of airtightness are a mandatory requirement in Passivhaus ULEH concept. The effects of this system for reducing heat losses though natural ventilation is quantified in Study 3A [Figure 187]. It confirms the significant energy impact incurred through the use of natural ventilation which almost doubles the SSHD in the coldest region in Scotland.

The study determines the reduction in SSHD due to high levels of airtightness illustrating

an 18% reduction from current standards to Passivhaus criteria in Orkney and therefore demonstrates the effectiveness of the MVHR. These reductions are relatively small, when compared with reductions through the MVHR or formal variations of the building envelope. However, high levels of airtightness can be achieved cost effectively with good design and workmanship using inexpensive materials.

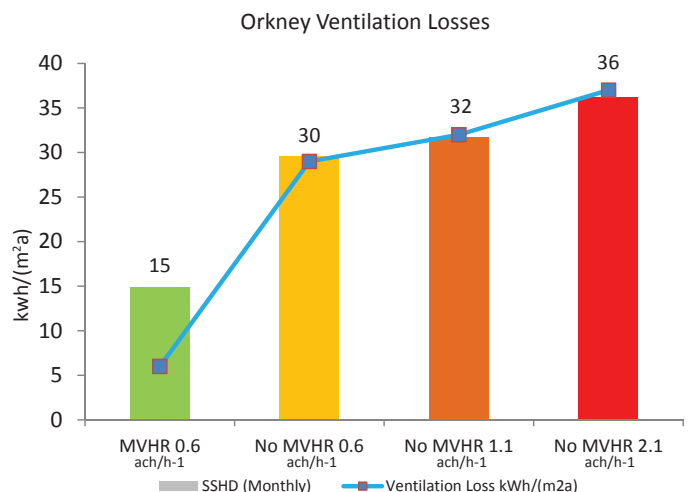


Figure 186- Ventilation Losses in Orkney

8.4. Building Form

Orientation and Technical Guidance Literature

The research literature review has found few documents concerning quantitative best practice guidance for designing ULEH in the UK and a lack of guidance for Scotland. Suggestions in contemporary ULEH guidance were found to be inappropriate for Scotland. The BRE's *Passivhaus Primer – Designer's Guide* states that deviation of more than 30° from South is likely to produce an increase of 30-40% in SSHD (McLeod et al. 2011). Research Study 2A demonstrated that there is a significantly higher increase of up to 165% in SSHD in some scenarios in regional Scottish climates.

The East of Scotland show increases in SSHD of 20 kWh/(m²a) using weighted u-values [Figure 188].

In study 2B, the increase

when altering a building by 30° in the East of Scotland was found to increase the SSHD by around 16.6%.

Conversely, when altering a building in Orkney by the same angle, the percentage increase can be as little as 8%. The variation in SSHD increase between orientations in different Scottish climates suggests that a wider range of orientations and therefore the urban forms could be more suitable for climates that are less responsive to solar gains. The research in Chapter 7 also proves that considered site placement of existing housing designs can have a positive effect by significantly reducing space heating demand by simply altering the orientation.

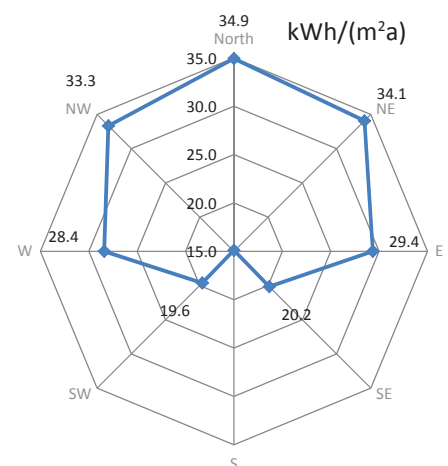


Figure 187- Orientation effect on SSHD (Weighted U-Values, East of Scotland)

Variation of Building Form

Studies such as 2C, 2D and 2E which explored changes to building form, confirmed generic best practice guidance suggesting that reducing the exposed surface area to reduce heat losses. Increased losses from the best practice flat roof to a traditional double pitched form in Study 2C can be balanced with a qualitative connection to traditional building form and the integration of solar panels for energy generation. Glazing Study 2E quantitatively highlights the relatively small impact that small areas of north facing glazing has on the SSHD demonstrating the possible implications of deviance from best practice in Scotland. The building typology Study 2D demonstrated the SSHD savings of using aggregated housing. The semi-detached house requires 26% less energy than the detached and the mid terrace requires 58% less than the detached house. [Figure 189] Due to the reduced losses the thermal envelope insulation for a mid-terrace typology in Orkney can be reduced by up to 110mm when compared to a detached typology. This suggests the energy and cost saving benefits for using aggregated housing, particularly in rural areas with harsh climates. Examples of terraced housing are commonly seen in traditional housing across rural Scotland, particularly in small towns and villages in contrast to the use of plotted development of single houses for groups of housing which relates to urban and suburban planning. The contextual design advantages of traditional housing grouping were reinforced as a 'common sense' alternative to suburban development as far back as 1941 in Building Scotland.

8.5. Building Form and Exemplars

The analysis of quantitative housing exemplars in Chapter 7 illustrated that the ULEH housing requirements for heat load can be achieved with little or no alteration to some designs such as the Boreraig, R2 House and Clousta in Orkney due to the low heat losses of the designs and low u-value.

The SSHD requirement can be achieved with alterations to the

R2 House using a thermal specification developed for a best practice prototype. Other optimised examples, such as the Boreraig house, require relatively unobtrusive optimisation to bring the SSHD close to the 15 kWh/(m²a) requirement at 17.1 kWh/(m²a). This illustrates the flexibility in some existing qualitative designs for use as ULEH models. In some of the designs the Study found significant alterations could significantly reduce SSHD and heat load. The SSHD of all of the NORD designs can be greatly reduced however, all requiring significant alterations to orientation and glazing design compromising the original design. The research also demonstrated that some of the designs would be unable to achieve ULEH targets even with significant variation to orientation and window design such as the Outer Hebrides Kit House. This illustrates

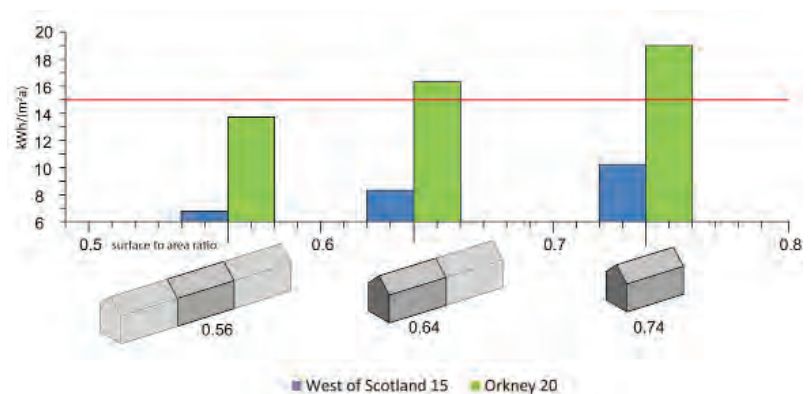


Figure 188- Dwelling Typology Results

the significant performance gap caused between best practice, low energy design and designs which appear to demonstrate no consideration of these principles.

Analysis of the designs show a trend of low SSHD with well orientated larger windows and a low HL with smaller windows. Generally, models that use larger, well-orientated windows as part of the initial design will perform well in terms of SSHD due to the use of solar gains to reduce overall heating requirement as best practice dictates. The houses with more traditional small window sizes tend to perform badly in terms of SSHD but generally perform relatively well in terms of heat load. This is due to the SSHD calculation considering overall heating requirement and heat load only considering worse case scenarios. When optimising for heat load, it would appear that colder climates require the reduction of heat losses in all parts of the building fabric and benefit from smaller areas of glazing. However, in climates with more solar gain, the increase in southern glazing can also decrease heat load due to the contribution of useful solar heat gains to heating requirement. The findings in Chapter 7 confirmed the results of the previous studies from Chapter 6 (2A, 2B, 2E), that the alteration to orientation and glazing has more of an effect in warmer sunnier climates. The study also demonstrated that variance from best practice generally led to a reduced percentage increase in Orkney, however this can be attributed to the increased performance of the thermal envelope, leading to lower heat losses when using the weighted u-values developed in Study 1B. The studies in Chapter 7 reinforce the importance of the consideration of form and design concepts are considered in parallel with energy efficient principles. The lack of energy efficient principles is particularly evident in designs such as the NORD housing examples whose SSHD reduced by around a third from optimised orientation alone.

Efficient Building form and Traditional Reference

Since the mid-1990s there have been more examples of contemporary rural architects referencing traditional forms and details developing more appropriate qualitative regionally responsive housing. In Chapter 7 the research confirmed that some exemplars developed by firms which use traditional reference such as Dualchas and Rural Design would be suitable for use as ULEH in Scotland with limited building form optimisation and slight thermal performance increases. The research found that the use or reinterpretation of selected traditional formal references are both suitable and can be beneficial to the future requirement for lower energy rural housing.

- Compact Forms
- Aggregated Housing
- Roof Form
- Referencing to the Regional Climate (Building thermal performance specification)

Some of these factors were highlighted in the approach taken by Rural Designs in the R-House, with its compact form and roof form that integrates the second storey accommodation. The study confirms that traditional form of the improved cottages with rectangular plans, steeply pitched roofs and compact forms can contain approaches that are suitable for reference in contemporary ULEH development with the relevant u-values and systems. The simple rectilinear plan forms create relatively efficient surface to area ratios with simple corner detailing that reduces the possible implications of cold bridging through complicated details. The large elevations created by the rectilinear form can accommodate large areas of south facing glazing.

Conversely the research demonstrated that the use of other traditional references such as complex volumetric building form layout and small windows can cause higher SSHD, therefore less efficient housing. This is illustrated by the Scotframe Clousta house type and the Proctor Mathews design. The use of small windows can be beneficial for reducing heat loads, but this should be coupled with compact forms to achieve efficient solutions.

There is a need to develop new innovative housing forms which need not directly reference traditional formal designs but still be suitable in rural areas.

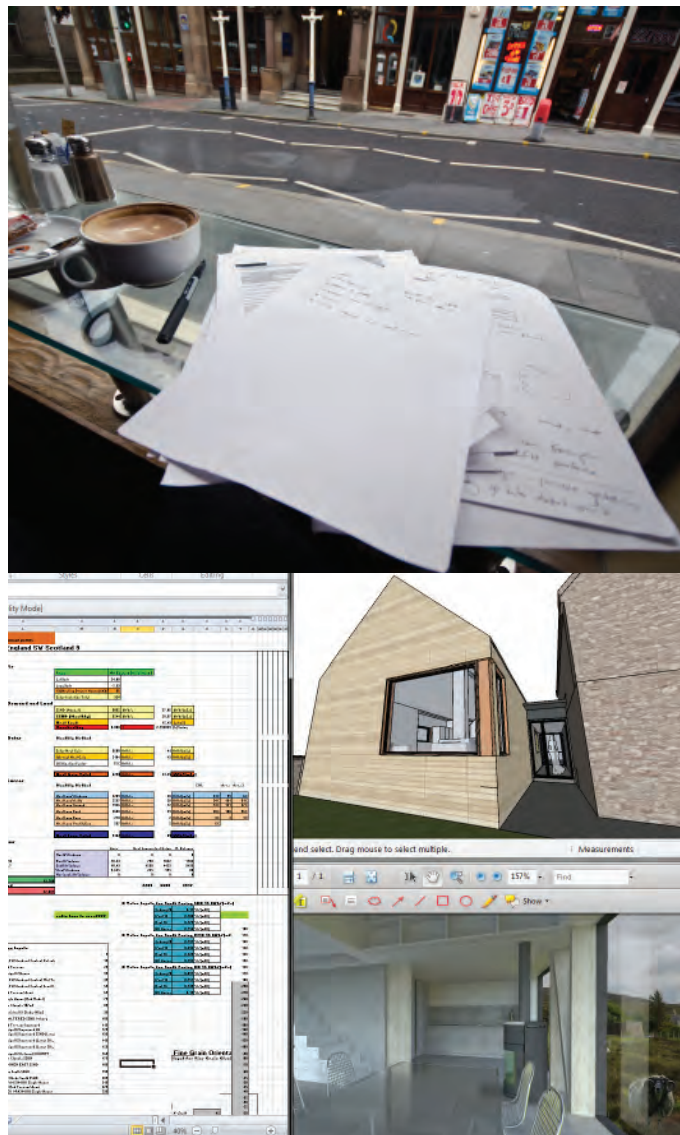
There is a need for more sophisticated architectural responses which use an abstraction of traditional forms such as the reinterpretation of the aggregated typologies and non-domestic typologies such as barns and courtyard clusters also present possible avenues for further design development.

8.6. Summary and Other findings

The slow progress on the carbon saving targets has been attributed to the economic climate and downturn (European Parliament 2010; Scottish Executive 2013a). The changing goal posts for ZCH in both England and Wales and the apparent disappearance of the Scottish ZCH target will have major implications for meeting the 2020 NZEB in Scotland. Current legislation negates regional variation, which has been proven to be a major factor on the energy use of housing in Scotland. Much of the current rural development utilises inappropriate development models and inefficient typologies. There is a requirement for a combined approach for appropriate rural housing and layout design, which responds to both the built environment and the requirement for lower energy housing. This combined approach of climatically responsive, low energy housing could decrease fuel poverty levels through lower bills and positively contribute to the Scottish countryside. This research has illustrated that ULEH requires consideration of specification, orientation, climate and design form at the concept stage due to these factors significant effect on the space heating energy performance. The research has proven the energy saving possibilities of aggregated housing forms. Use of these forms offer an suitable alternative to the overused, heavily criticised detached housing typology. Increased consideration of best practice solar design principles will reduce the cost of achieving ULEH and therefore ZCH and NZEB. Designing with a combined approach to context and energy efficient forms will allow for a more efficient building form which will require fewer costly fabric performance increases to reach ULEH levels through efficient and considered use of the relevant factors. The research found a need for more awareness, guidance and education regarding best practice, low energy and passive solar principles in order to increase cost effectively reduce energy consumption and carbon emissions. The studies in Chapter 7 illustrate the unfamiliarity or rejection of these principles can make reaching ULEH targets impractical, if not unobtainable. The design of new development layouts that respond appropriately to orientation, surrounding built context and combined with the reference of appropriate energy efficient forms will improve space heating performance therefore lower heating costs without the increase in building specification. The contemporary rural context requires housing forms that are appropriate to the rural landscape but also designed to use less energy with an appropriate specification for their regional environment.

FUTURE WORK

Chapter 9



9. FUTURE WORK

This section discusses future work beyond the present findings.

Development of Suitable, Regional Housing Models

The predominantly quantitative approach taken in this study has not allowed for an exploration of regional and critical regionalist principles and their relationship with climatic variation and energy use. However the quantitative findings from the research could provide a gateway to promote regional variation in housing form and more responsive solutions to place and landscape whilst addressing the requirement for lower energy housing. Further work is required to determine regional housing models that efficiently and appropriately respond to both climatic variation and regional design. The results of the research demonstrate the requirement for housing form and specification to be tailored for different regions across Scotland due to climatic variation. This will ensure cost effectiveness and predictable high performance levels. This approach to building performance specification coupled with the specific formal design could be demonstrated through the development of a series of new regional housing designs. These could be developed in partnership with timber kit manufactures as more appropriate 'kit' houses suitable for self-builders. Alternatively the development of low cost, high efficiency housing using best practice principles highlighted in the research such as aggregated housing forms could be developed with housing associations to combat fuel poverty in rural areas.

Studies Expansion

Chapter 6 Expansion

The studies contained within chapter 6 include a limited number of variables which utilise a single house design. A further development of this study is required to expand the variables tested. The analysis of similar variable's used in chapter 6 on alternative plan forms, layouts and designs would further develop the knowledge base of ULEH. The implications of changes to the variable studies in Chapter 6 are likely to have slightly different effects on differently designed and scaled housing designs. The generation of a wider range of qualitative results would allow for the development of more expansive guidance documentation.

Chapter 7 Expansion

The methodology defined in chapter 7 is suitable for a more expansive series of studies to determine the building forms effect on SSHD, heat load and various other performance metrics. A more exhaustive optimisation study using a greater range of house designs could further demonstrate the viability of optimised existing housing designs as ULEH. This study could take a similar approach to the Polnoon re-design study which uses typical suburban housing designs and adapts them to be more appropriate in a rural setting through simple material and elevation variations. Instead of re-designing existing designs for appropriate relationship to context, optimise them for lower heating requirements on a region by region or site by site basis.

Cost Effectiveness Research- Form versus Specification

This research demonstrates the requirement for regional solutions for ULEH, this can be achieved through more insulation or higher specification insulation materials, but will increase material costs. The research demonstrates that reduction of SSHD can be also achieved using more efficient building designs, optimised orientation and reduced losses through ventilation. There is a requirement for a proven cost effective approach to all of these variables in particularly rural areas where there is a requirement for low construction and running costs to reduce fuel poverty. More detailed research is required to establish the required performance specifications in different regions using a wider range of designs. This will allow for a cost effectiveness study between increased thermal performance and optimisation of building form.

Development of Aggregated Housing Forms

Suitable alternative approaches for development are required in rural areas. The finding of the research highlighted the energy saving possibilities of aggregated forms. A development was considered that would involve using interpretations of larger rural typologies to house multiple units. The proposal for the development of non-domestic typologies into a series of aggregated housing prototypes was deemed too extensive to include in the research. The utilisation of larger forms that integrate multiple units in single volume in order to reduce the exposed surface area will greatly reduce heat loss when compared with detached housing typologies. The conceptual design of the single volume would relate to larger non-domestic types found in rural settings such as barns, courtyards and agricultural sheds. The current development layouts involve a spread of individual houses across a large land area that creates a low-density fragmented plan layout. Using larger scale agricultural forms would alter the appearance groups of homes have on the rural environment. The use of larger built forms would be intended to be seen as a larger individual form. This would relate to the landscape as more familiar agricultural building rather than a group of smaller detached residential buildings. The development of this project lends itself to a series of design studies and research papers to prove its viability for actual development.

Guidance Notes

It was not in the remit of the research to produce a technical guidance document for stakeholders working in new rural development. However, the research has highlighted the requirement for such a guidance document due to the lack of information available and the significant impact that factors investigated in the research have on heating performance. The issue of the effect that regional climatic variations has on the heating requirement of housing in Scotland requires more research if new ZCH and NZEB are to perform to their targets. The results and format of the research are not suitable for immediate use as detailed design guidance applicable for developments in rural areas. However, the results of the research contain a sufficient amount of new knowledge to provide an estimation of the impact of regional site climate, orientation, specification and the impact of formal design decisions on the heating requirement of housing.

Simple guidance could be generated from the findings contained in this research to give broad quantitative implications of designing housing in different regional areas in Scotland. The guidance could be distributed and used similarly to that of the Planning Advice Notes. An expansion of study to contain more variables, house designs and plan types using the same research methodology and development of PHPP would be possible to explore the effects of more specific alterations. The methodology defined in the research using PHPP as a research tool could be used to develop more research studies extending the variables used in this research.

PHPP Customised Master File in Practice

A version of the customised PHPP front page would be suitable to develop into a simple tool for designers as a precursor to performing a full PHPP calculation. The vast reduction of inputs to give a Space Heat Demand or Heat Load figure would allow a designer to gain a rough estimate of the energy efficiency in any of the Scottish climates. Further work on the Excel Master file spread sheet that controls the PHPP climate calculation files could aid the generation of a more powerful research tool that is capable of more complex studies.

The current multiple climatic zone methodology developed for PHPP would be suitable for further research projects or designers wishing to rapidly test prototypes in different areas. This could be applicable for firms such as Dualchas, Rural Design and Neil Sutherland Architects who produce kit houses for use in different areas in Scotland.

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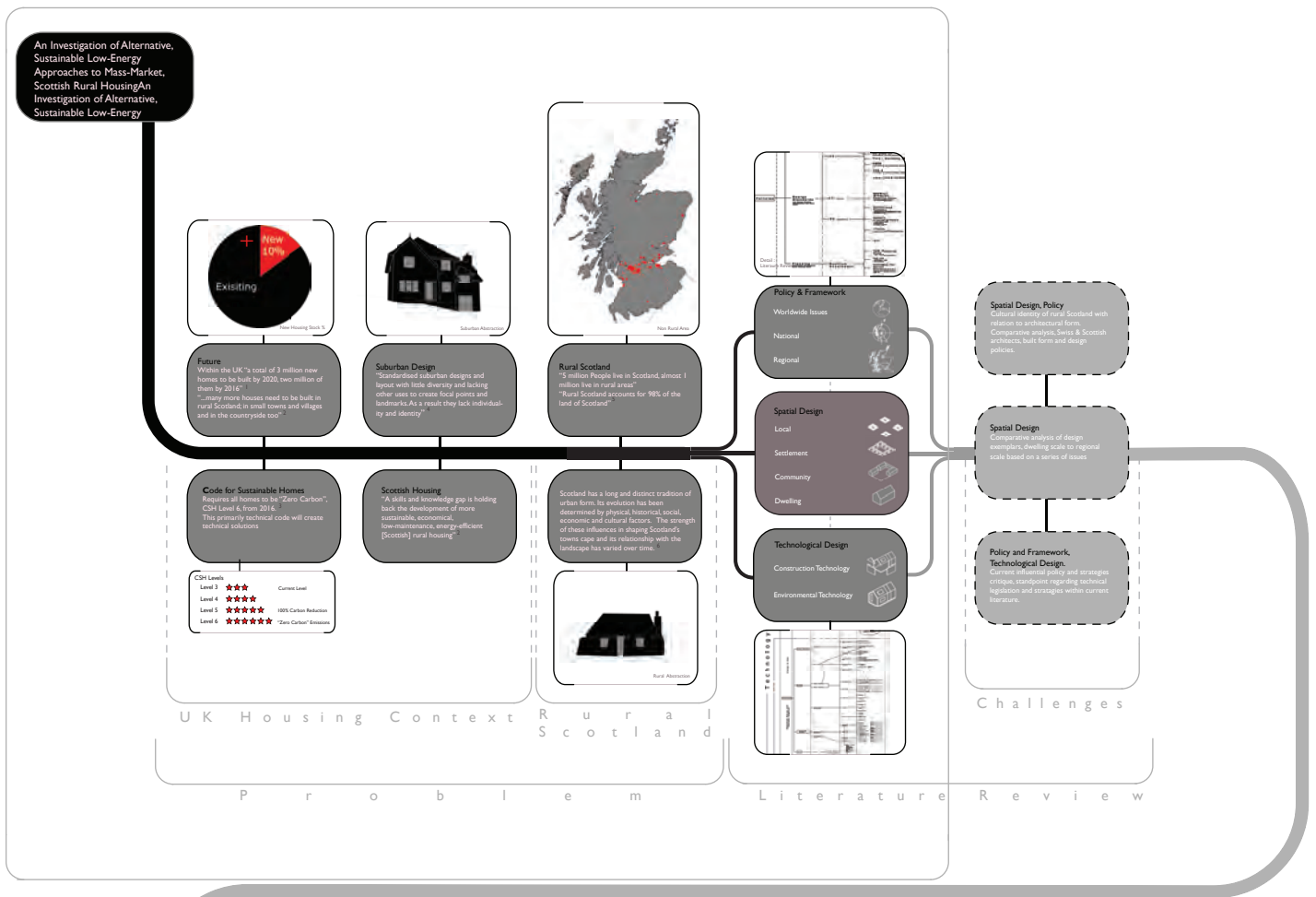
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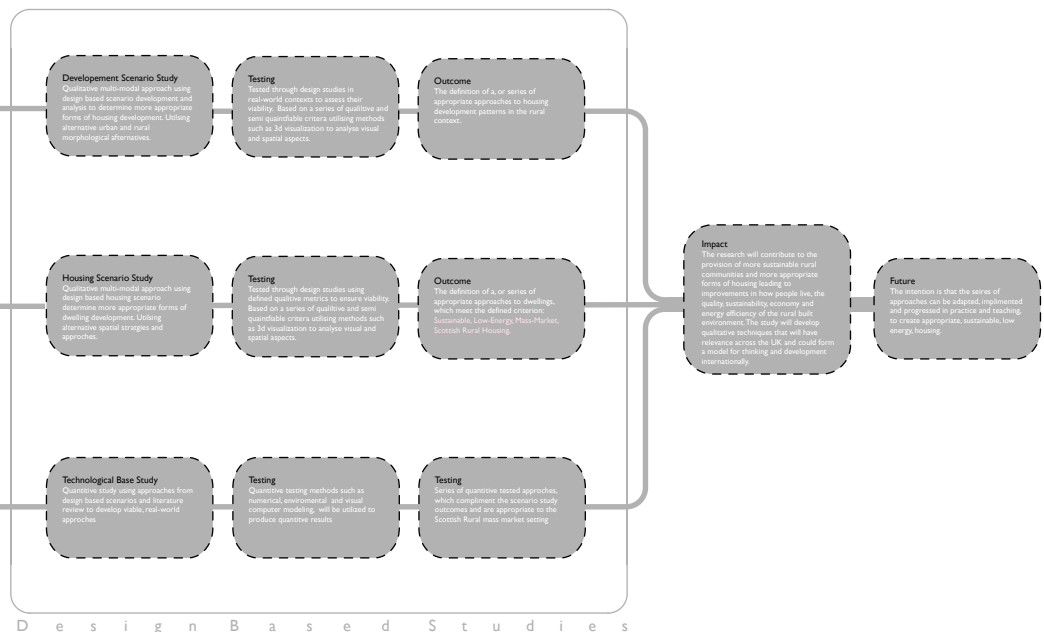
APPENDICES

Chapter 11





Synthesis of Literature Review
Development of a number of theoretical standpoints which will be tested through the following design based studies.



An Investigation of Contextually Responsive Ultra Low Energy housing in Rural Scotland: A Case Study

PhD Research Project
Alex Pearson



Aims of Study

The aim of the study is to analyze the effect of regional climatic variations on the heat energy requirement & heat load of houses in rural Scotland.

The overall aim is to define the design envelope for development of more nuanced and qualitative approaches to ultra-low energy, rural housing in regional Scottish climates. The study attempts to balance qualitative design considerations with quantitative energy use issues.

Rural Scotland



Research Questions

Can alternative variations of existing housing be developed to become more energy efficient and more specific to their regional context?

To what effect does the building form define the energy requirement across Scotland?

How can altering the building form and typology improve the qualitative aspects of regional rural housing?

Scottish Mass



Swiss Regional



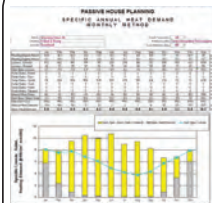
Methodology

Primary quantitative findings are defined in the Quantitative Parameter Study using thermal analysis software.

The Quantitative Parameter Study (Discussed in detail below) and the Housing Design project uses the Passivhaus (A German ultra-low energy concept) Planning Package (PHPP) for thermal analysis of prototypes and design options.

Qualitative elements of the study will involve case study analysis of key examples regional architecture and typologies (UK & Europe). Through design studies elements of these examples will be developed to create more nuanced, energy efficient housing for rural Scottish regions.

PHPP: Heat Demand



PHPP: Climate Data Input

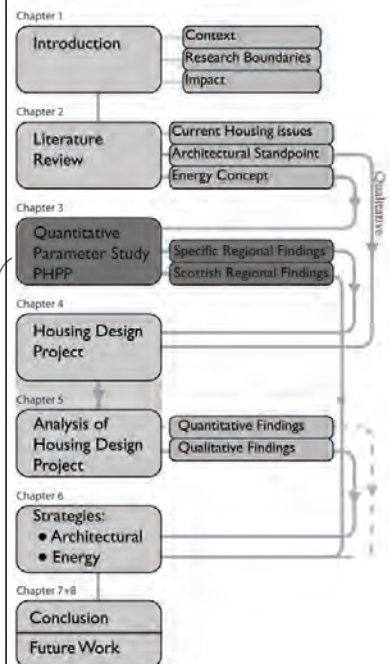


Passivhaus, UK



Thesis Structure

An illustration of the thesis structure, the study highlighted is described on the following page. To illustrate the connection and balance between Quantitative & Qualitative linkages are shown. The housing design chapter concentrates on the typological and formal design.



Quantitative Parameter Study PHPP

The study quantifies the effect of varying architectural parameters on the energy performance of a housing prototype in different regions in order to achieve more appropriate regional solutions to ultra-low energy housing (ULEH) in Scotland. The study uses three basic study prototypes tested against three study categories; with a series of variable.

Study Prototypes	Study Categories	Study Variables
Basic Forms	Exposed Surface Area/ Volume Ratio Studies	Plan Form Building Typology Storey Height Roof Design
	Heat Gains and Losses through Envelope Studies	North & South Window Areas
Prototype House Design	Building Location Studies	Scottish Regional Location European Location Orientation Fine Grain Deviation from South

An Investigation of Contextually Responsive Ultra Low Energy housing in Rural Scotland: A Case Study

PhD Research Project
Alex Pearson



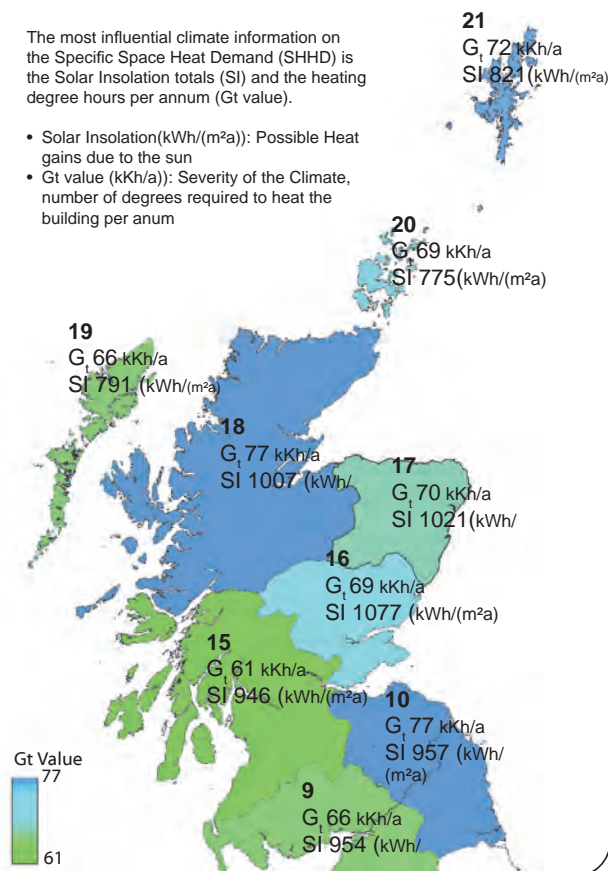
Quantitative Parameter Study Selected Preliminary Results

These results are based on the 107m² housetype design prototype which meets the Passivhaus Ultra Low Energy criteria. The housetype defined the base technical specification of the other prototypes and served as a way of assessing

Scottish Climate Variation

The most influential climate information on the Specific Space Heat Demand (SSHD) is the Solar Insolation totals (SI) and the heating degree hours per annum (Gt value).

- Solar Insolation(kWh/(m²a)): Possible Heat gains due to the sun
- Gt value (kKh/a): Severity of the Climate, number of degrees required to heat the building per annum



Housing Prototype

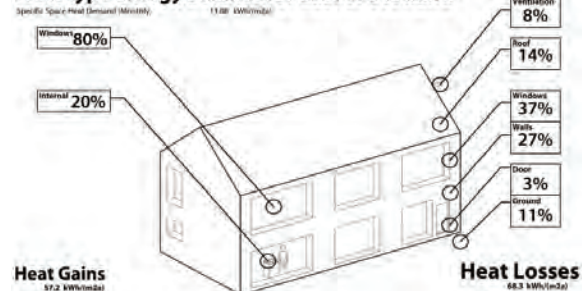
Specification

3-4 bedroom, prototype house with 107m² TFA, specification meets PH certification

- 50% South Glazing (30.4m²)
- Surface\ Volume: 0.73
- Minimal North Glazing ~6%
- Exposed Surface Area: 317m²
- 90% Efficient MVHR Unit

Average U-Values:

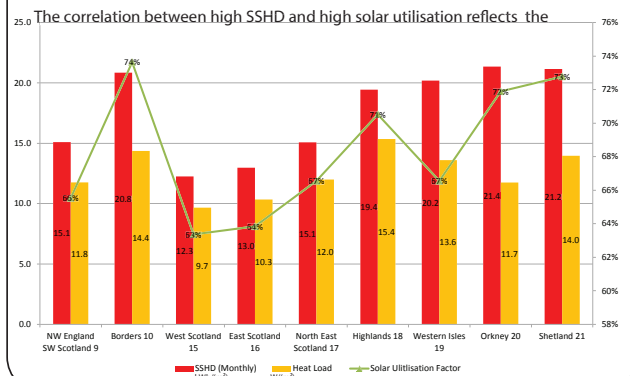
Prototype Energy Balance for East of Scotland



Regional Climates Effect on Heat Demand

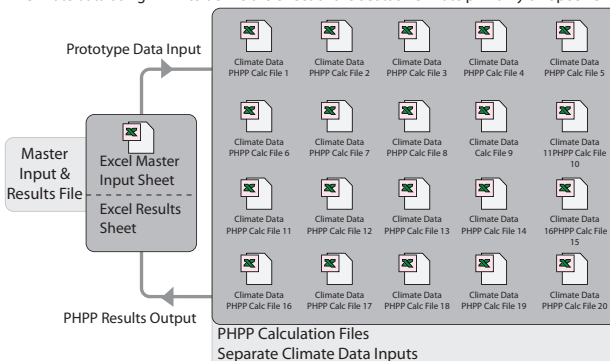
The graph illustrate the difference across Scotland in heat demand and Heat

Load on the fixed prototype, showing an maximum difference of 46% (SSHD).



PHPP Analysis Workflow

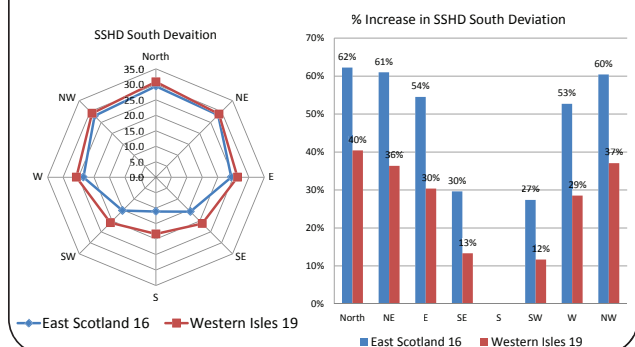
The Quantitative Parameter Study tests prototypes altering certain values with multiple climate data using PHPP to define the effect of the Scottish climate primarily on Specific



Orientation Effect on Heat Demand

East of Scotland climate is more solar gain reliant than other climates across Scotland

(Higher increase of SSHD), using larger windows in this climate would be more beneficial



An investigation of Contextually Responsive Ultra-Low Energy Housing in Rural Scotland: A Case Study PhD

Housing development across Scotland, particularly in rural areas has little relationship with the built and current energy context. Houses are generally built using suburban designs, which are inherently not energy efficient and do not fit into the rural context. The doctoral research seeks to develop a design approach which is a balance between energy use and contextual design in new, regional, rural Scottish, mass market

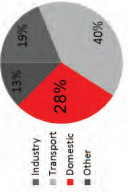
Contact:



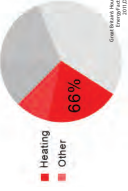
This board illustrates key sections of a project which defines the design envelope for achieving regional solutions to very low energy housing in Scotland. The study investigates the design constraints on developing alternative forms of ultra-low energy housing that respond appropriately to the regional Scottish context in terms of people, climate and landscape. It quantifies the effects of varying key architectural parameters on the energy performance of prototype house typologies across the different climate regions in Scotland. This parametric study uses the Passive House Planning Package to establish three typological houses that are manipulated in terms of plan orientation, the ratio of area of glazing to area of external envelope, roof form and roof pitch. These criteria are used to better understand how building form, site positioning and fenestration are affected by climatic variation across the different Scottish climatic regions. Furthermore, the study quantifies the extent to which these important architectural criteria can be manipulated whilst still satisfying the requirements of very low energy space heat demand and micro-renewable energy generation.

This is used to establish the extent of the design boundary conditions within which more qualitative, nuanced and regionally responsive architectural solutions to Scottish housing can be developed.

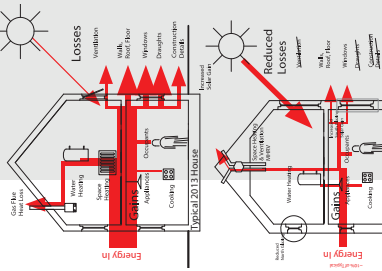
UK Energy Total Use



Domestic Energy Use



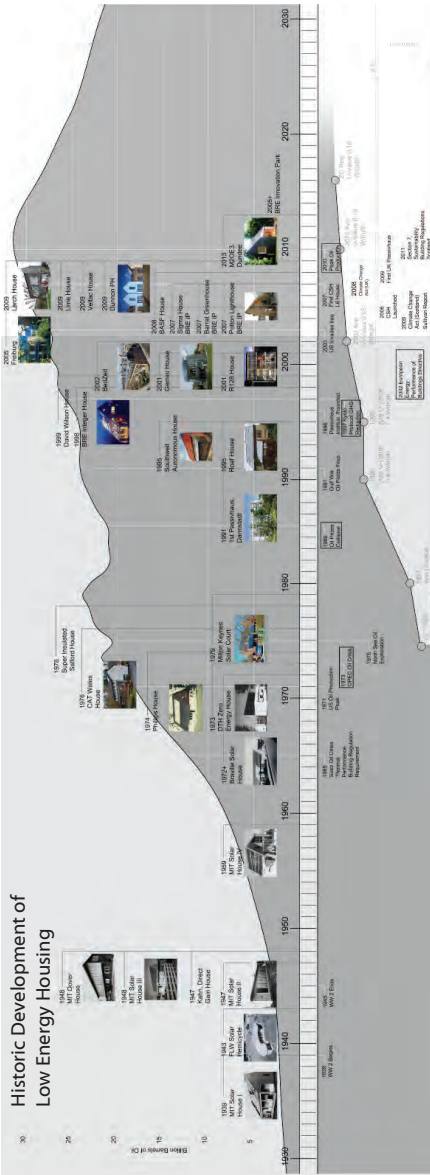
Domestic Heat Gains & Losses



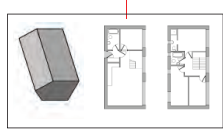
Passivhaus & UK Legislation Comparison

Code for Sustainable Homes Level 6 (England) & Act	Section 7, Gold Standard	Passivhaus
Carbon Dioxide Emissions	0 kgCO2/m2/a OR 10-11 kgCO2/m2/a +	Not Specified
SHED Max Allow	46 kWh/m2a (Semi-Detached) 30 kWh/m2a (Mid Terrace)	15 kWh/m2a
Air Tightness	10 m3/h.m2 @50 Pa 30 m3/h.m2 @50 Pa	1 m3/h.m2 @50 Pa 0.6 m3/h.m2 @50 Pa
Windfall	30 m3/h.m2 @50 Pa 30 m3/h.m2 @50 Pa	0.6 m3/h.m2 @50 Pa 0.6 m3/h.m2 @50 Pa
Assessment Method	SAP 2009/12 UK Average Climate Data	PHPP Regional Climate Data


Historic Development of Low Energy Housing



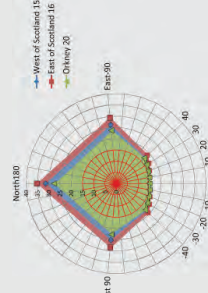
Quantitative Variables Project Structure



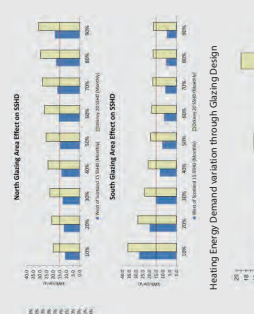
Key Project Findings



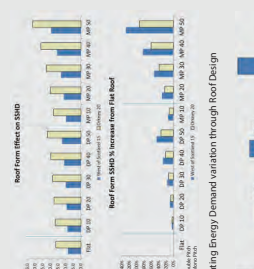
Effects of Orientation on Heating Energy Demand 15 kWh/m2a at South Orientation



Heating Energy Demand Variation through Glazing Design



Heating Energy Demand Variation through Roof Design

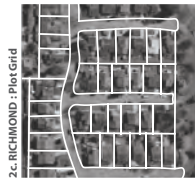
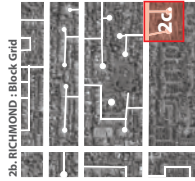
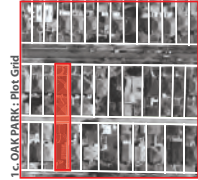
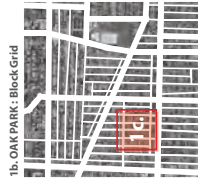
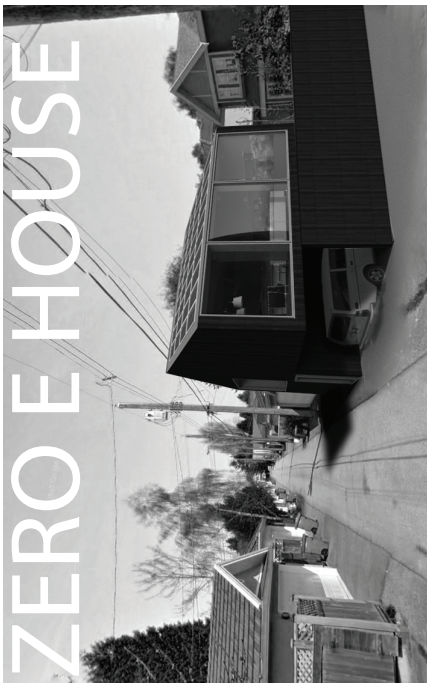


PHPP Results

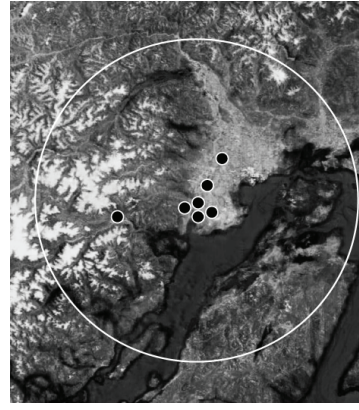
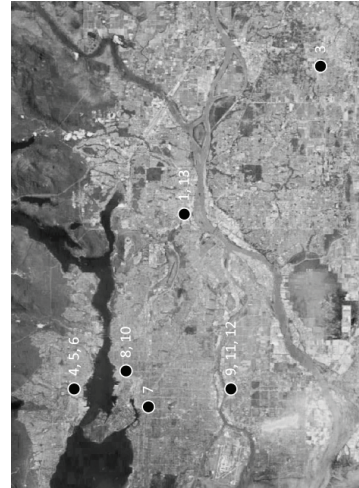
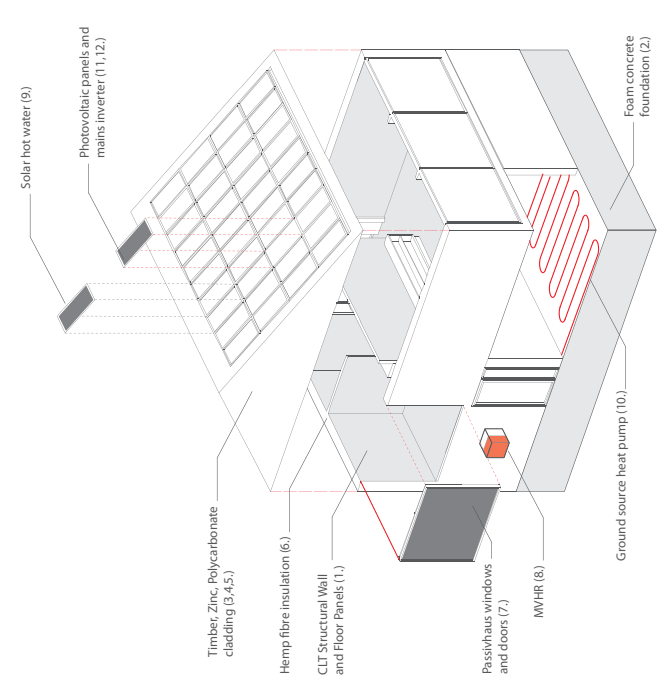
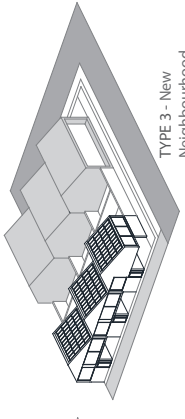
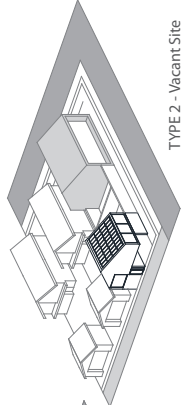
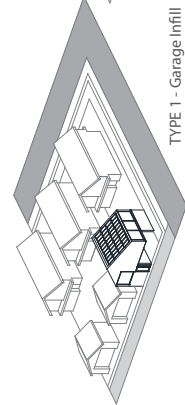
Tested in Scottish Climatic Areas with PHPP

Architectural Parameter Alteration

- Typology
- Orientation
- Glazing



URBAN DENSIFICATION STRATEGY



MATERIALS, COMPONENTS AND SYSTEMS

CONSTRUCTION:

1. CLT superstructure
CST Innovations, 20 Brad Street, New Westminster, BC
2. Foam concrete foundation
Great Pacific Furnice Inc., 1980 Centennial Way, Squamish, BC

CLADDING:

3. Polycarbonate
Laird Plastics, Vancouver, 9275 194th Street Unit B5, Surrey, BC
4. Timber
Dicks Lumber, 160 Hanes Ave, North Vancouver, BC
5. Zinc
Vancouver Metal Roofing Ltd., 1095 3rd Street West, North Vancouver, BC
6. Insulation
Dicks Lumber, 160 Hanes Ave, North Vancouver, BC
7. Passivhaus Windows / Doors
Building Evolution, 718 Millard, Vancouver, BC

MECHANICAL:

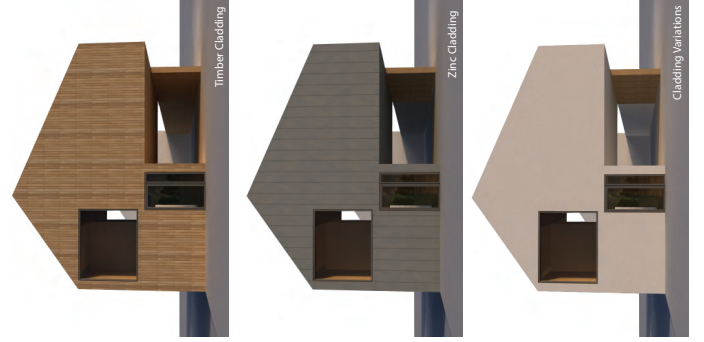
8. MVHR (+Post Heater - Elec/DHW)
Sandford Heat Exchangers Ltd., 1250 Pender St E, Vancouver, BC
9. Solar Hotwater
Renewable Future Energy Resources Inc., 190-2188 5 Road, Richmond, BC
10. Heat Pump
Exchange Energy Inc., 1305 Powell Street/Vancouver BC V6L 1G8 CANADA

ELECTRICAL:

11. Photovoltaics
Renewable Future Energy Resources Inc., 190-2188 5 Road, Richmond, BC
12. Inverter (Mains Feedback)
Renewable Future Energy Resources Inc., 190-2188 5 Road, Richmond, BC

INTERNAL FINISHES:

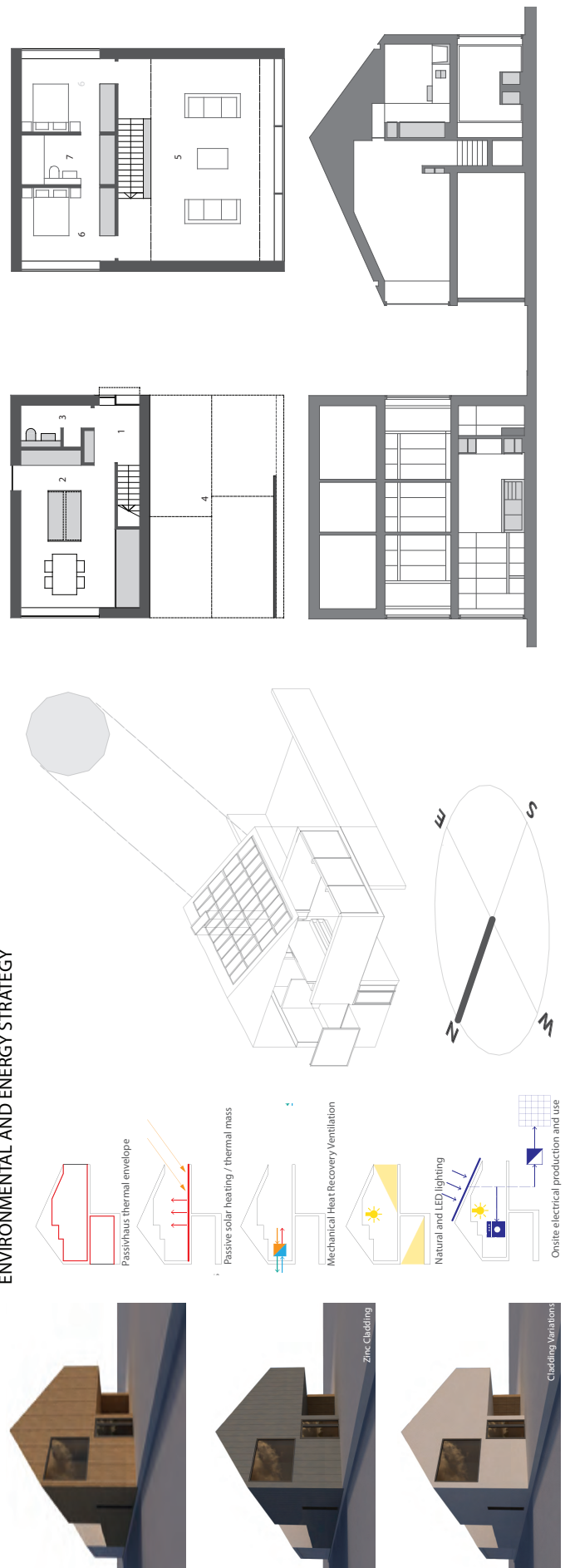
13. CLT
CST Innovations, 20 Brad Street, New Westminster, BC



ZERO E HOUSE



ENVIRONMENTAL AND ENERGY STRATEGY



100 Mile House, Zero E House Competition Board, in Collaboration with Neil Burford and Joseph Thurrott, 2012

HOUSE WITH A SECRET ROOM

